U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 501

Distribution of Metals in Elizabeth River Sediments

Environmental Protection Agency, Annapolis, Md

Feb 74

PB 260 501

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NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA 903/9-76-023

DISTRIBUTION OF METALS IN ELIZABETH RIVER SEDIMENTS

June 1976

Technical Report No. 61

Annapolis Field Office

Region III

Environmental Protection Agency

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BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	

4. Title and Subtitle

DISTRIBUTION OF METALS IN ELIZABETH RIVER SEDIMENTS

5. Report Date: June 1976

6.

EPA 903/9-76-023

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

U.S. Environmental Protection Agency
Annapolis Field Office
Annapolis Science Center
Annapolis, Maryland 21401

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

U.S. Environmental Protection Agency
Region III
6th & Walnut Streets
Philadelphia, PA 19106

13. Type of Report & Period Covered

Metals, February 1974

14.

15. Supplementary Notes

16. Abstracts

In order to develop a current inventory of metals contamination of the Elizabeth River, sediment samples were collected at 96 stations in February of 1974 and analyzed for Cd, Cu, Cr, Hg, Pb, Zn, Al, and Fe using atomic absorption spectrophotometry. Concentration levels were compared with levels found in another highly industrialized harbor complex, other estuarine systems and in Chesapeake Bay sediments geographically removed from the study area. Distribution patterns of various metals are outlined for reference to various inputs. Possible mechanisms for transport and distribution are discussed.

17. Key Words and Document Analysis. 17a. Descriptors

Metals in sediments
Elizabeth River sediments
Metal contamination

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

1a

18. Availability Statement

TIS

19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 100
20. Security Class (This Page UNCLASSIFIED	22. $5.00-300

NTIS-35 (REV. 3-72)

USCOMM-DC 14952-

EPA 903/9-76-023

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Technical Report

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ABSTRACT

In order to develop a current inventory of metals contamination of the Elizabeth River, sediment samples were collected at ninety-six (96) stations in February of 1974 and analyzed for Cd, Cu, Cr, Hg, Pb, Zn, Al and Fe using atomic absorption spectrophotometry. Concentration levels were compared with levels found in another highly industrialized harbor complex, other estuarine systems and in Chesapeake Bay sediments geographically removed from the study area. Distribution patterns of various metals are outlined for reference to various inputs. Possible mechanisms for transport and distribution are discussed.

INTRODUCTION

The Elizabeth River is a tributary of the James River located in Virginia. The river is largely estuarine in nature and as such is a physical and chemical mixing zone. A major physical characteristic of any estuary is that its volume and comparatively sluggish tidal cycles slows the inflow of fresh water. As a result of this decreased velocity the load of suspended matter introduced into the system settles to the bottom, rendering the sediment a reservoir for a diverse and heterogeneous accumulation of material, much of which may have potential toxic properties (1). This natural condition tends to create a "sink" for many metallic compounds due to their reactions with particulate matter. Heavy industrial loadings increase the potential toxicity of the bottom sediments to aquatic life.

The Elizabeth River is an example of an excessively utilized waterway in regard to waste assimilation. Due to its relatively shallow nature, the low dispersion and transport characteristics mentioned above, accompanied by low freshwater flow rates, and its intensified industrial, commercial and domestic development, the Elizabeth River's ability to assimilate the diverse waste input from these sources is severely limited. These inputs from other than natural sources take many forms. Discharges from primary treatment plants contribute to the widespread water quality problems associated with this area. The overflow of pumping stations

has contributed to the high coliform levels in the receiving waters. Progressive stream fertilization by domestic and industrial waste inputs, primarily from nitrogen and phosphorus, has contributed to recurring eutrophication problems. Industrial and commercial inputs from varied chemical and domestic processes add further to the burden of the river. Fish kills, frequent reports of oil spills, and other accidents associated with shipping lanes further characterize the pollution problems in the Elizabeth River (2). Richardson (1971), in a study of the benthic community of the Elizabeth River, found the dominant organisms to be those types that are pollution tolerant, with wide geographic range, and which rarely dominant other communities except under stress conditions. "Non-selective deposit feeders were found in low numbers because of the lack of oxygen and high concentration of hydrogen sulfide found in the deposits below 1 cm. Suspension feeders and selective deposit feeders were favored because of the good supply of well aerated detrital material in the sediment surface and trapped in abundant oyster shells." (46) A similar study by Boesch (47) reported the same result - the Elizabeth River is characterized by the presence of pollution tolerant species.

Although it is not the intent of this effort to deal with toxicological effects in any detail, it should be noted that the State of Virginia has found some areas of the bottom toxic to fish (1), the Virginia Institute of Marine Science has reported high levels of Pb (550 ppm), Hg (3 ppm), Zn (1200 ppm), and Cu (300 ppm)

in bottom sediments (2), and the Bureau of Shellfish Sanitation has designated the Elizabeth River a "condemned area" for the direct marketing of shellfish (16). The oysters must be placed in a cleansing area for a fifteen (15) day period prior to sale. Zn (>> 2000 ppm), Cu (25-100), and Cd (1.0 - 2.0 ppm) values have been found in Elizabeth River oysters (36). Although it is not necessarily unusual to find such elevated levels (levels of 20,000 ppm have been found near outfalls disposing zinc (50)), inputs manifested in the biota to such a degree may be of public health significance. Certainly the ability of the oyster to concentrate metals is well documented (50, 51). What remains unclear is the mechanisms of transfer from the sediment or water phase to the biological phase, and since little information exists on the bioavailability of these elements, it is difficult to correlate a given, measured concentration of a metal with a specific toxic level. Considerations such as chemical bonding of the metallic species (11), particle size of the substrate (12), valence state and humic acid availability (13), synergistic and antagonistic mechanisms all relate to the reactivity of a given metal. The toxicity in terms of LD_{50} of various metals has been well documented (3, 4, 5) and large scale outbreaks of metal poisoning (6, 7, 8, 9, 10) illustrate the potential health hazard of these substances. The relationship between acute high level doses to test organisms under laboratory conditions versus chronic low level, long term effects in the environment remains a question.

Even though the mechanism of exchange from the physical to the biological is unclear there can be no doubt that such a mechanism exists. The implications of this exchange is important as it relates to the impact of dredging and open water disposal of dredged spoil. At present, all dredged spoil from the Southern Branch of the Elizabeth River is disposed of in a specially constructed dyked area - Craney Island (36). Drifmeyer and Odum (1975) investigated dredge spoil as a possible source of metals uptake by salt marsh biota using Craney Island as one of the study areas. The spoil itself was classified as polluted, highly organic (9.6 % loss on ignition) and as a silt-clay complex (45). Marsh grasses showed significantly higher levels of Pb and Zn in the spoil area compared to the control area. Pb and Mn were also higher in grass shrimp from the spoil area. Pb values in fish were higher in the spoil ponds. Drifmeyer concluded that dredge spoil, even though disposed of in a contained area, may act as a source of certain heavy metals that are potentially toxic to the biota (45).

For reference purposes the toxicity of some heavy metals is presented in Appendix IV, Tables 21 and 22.

Sampling programs spanning several years have been carried out by various private and public institutions. Each of these studies has provided valuable data for the area studied. This study is an effort to provide a synoptic picture of the metals accumulation in the Elizabeth River sediments.

SUMMARY AND CONCLUSIONS

1. This report provides an inventory of present conditions relating to metals contamination of Elizabeth River sediments.
2. Concentrations of all metals analyzed in the Elizabeth River sediments were two (2) to ten (10) times greater than sediments from the mid-Chesapeake Bay.
3. Distribution of metals generally reflected the inputs from heavy industrial, commercial and domestic sources which the Elizabeth River receives.
4. Metal concentration ratios between the Elizabeth River sediments and Chesapeake Bay sediments follow a pattern (Cu > Pb > Cd > Zn) suggesting that in black colored sediments from the Eastern and Southern Branches, Cu, Pb, Cd, and Zn may exist as sulfides since the order for solubilities of divalent sulfides exhibits the same pattern. In the Main Branch the ratio pattern in black sediments suggests that these metals are probably present in forms other than sulfides. Provided the metal sulfide solubilities are low, the deposition as a sulfide would be one mechanism of the sediment acting as a "sink". Additionally, so long as the metals are tightly bound in the sink, their bioavailability would be lessened and the metals would therefore be unavailable for introduction into the biological segment assuming that the system is not disturbed.
5. Non-linear relationships between metal and aluminum/metal ratios suggest that Cu, Cr, Pb and Fe are not associated with the clay

mineral portion of the sediment.

6. No black sediment was found in the Western Branch. Being the least industrialized of the various branches it does not receive the quantities of organic materials, sulfides, etc. to which the other branches are exposed. The black color has been related to hydrotrolite which depends on the presence of sulfide and poorly oxygenated water for its formation (23). Such conditions apparently do not exist in the Western Branch.

7. Better than half of the total number of black sediments found in the study area had distinct "air" pockets in the core when the sample arrived at the laboratory for analysis. No gray samples showed this phenomenon. It is possible that the black sediments were evolving H_2S which is characteristic of hydrotrolite. The absence of gas in gray samples, the sulfide solubility pattern and the correlation between water content and color support this conclusion.

8. A pronounced difference in water content between the black and gray sediments was evident. The correlation exists for the entire study area, excluding the Western Branch which had no black sediments, and is very pronounced in the Southern and Eastern Branches. No explanation is offered for this phenomenon although some references indicate that the presence of hydrotrolite in some way contributes to the high water content found in black sediments (23).

9. Particle size can play a significant role in adsorption reactions of metallic species. The appearance of the sediments was recorded as the sample was removed from the core. The sediments of the Elizabeth River appear to be of a silt-clay nature and were uniform in appearance throughout the study area in terms of size. Differences in color were noted and recorded.

10. Examination of the four major river divisions revealed the following:

    a. The entrance of the Elizabeth River at Craney Island shows high concentrations of Cr, Fe, and Al, with lesser amounts of Zn. Pb, Cu, Cd and Hg increase in concentration moving in a southerly direction as the branches are approached.

    b. The Eastern Branch has very high concentrations of Cu, Pb and Fe, with slightly lesser, but still high concentrations of Zn, Cr, Cd, and Al.

    c. The western side of the Southern Branch showed very high concentrations of Pb and Cu, with Cr, Zn and Cd also high. The eastern side showed lesser amounts of all metals except Cd and Hg which are equally distributed on both sides.

    d. The Western Branch had several areas that were very high in Al, Fe, Pb, Zn, Cd, Cu and Cr.

11. Comparison of the Elizabeth River with other estuaries revealed the following:

    a. Concentrations of all metals analyzed from the Elizabeth

River were two (2) to ten (10) times greater than concentrations found in the Chesapeake Bay.

b. The Elizabeth River showed three (3) times the Pb and Zn concentrations found in the James River (river miles 0 - 84), but slightly less Hg was found in the Elizabeth. The James River shows little accumulation of Pb and Zn compared to the Chesapeake Bay, although Hg was five (5) times greater than in Bay sediments.

c. The Elizabeth River concentrations for metals analyzed were from two (2) to ten (10) times the concentrations reported for the Potomac River.

d. The Delaware estuary shows consistently higher than ambient levels that are similar to the levels found in the Elizabeth River.

e. Average Zn and Cd concentrations in Baltimore Harbor were twice (2) the levels found in the Elizabeth River. Baltimore Harbor showed four (4), five (5) and eleven (11) times the concentrations of Pb, Cu and Cr, respectively, found in the Elizabeth River.

GEOGRAPHICAL DESCRIPTION

The Port of Hampton Roads, Virginia, including the cities of Norfolk, Portsmouth, Chesapeake, Newport News, and Hampton, is the largest port complex in Virginia, in fact, one of the finest natural harbors in the world. The combined population of the cities located around Hampton Roads was 725,624 in 1970 (14). Hampton Roads is located at the southern end of the Chesapeake Bay, approximately in the middle of the Atlantic seaboard, 300 miles south of New York, 180 miles southeast of Washington, D.C., and 20 miles west of the entrance of Chesapeake Bay (Figure 1).

Hampton Roads is the largest bulk cargo exporting port in the United States, with bituminous coal being the principal export. Tobacco and grain exports are also among the world's largest. The following table lists the most common items exported from Norfolk Harbor in 1971.

Principal Exports - Norfolk Harbor - 1971[1]

Commodity	Short Tons	% of Total
Coal and lignite	25,047,034	90.60
Corn	875,748	3.16
Grain mill products	284,440	1.02
Wheat	135,981	0.49
Coke, petroleum products, asphalts, solvents	122,205	0.44
Tobacco	101,856	0.36
Iron and Steel Scrap	96,911	0.35
All others	989,678	3.58

[1] "Waterborne Commerce of the U.S.," Calendar Year 1971, Part 1, Waterways and Harbors of the Atlantic Coast, Department of the Army, Corps of Engineers, 266 p.

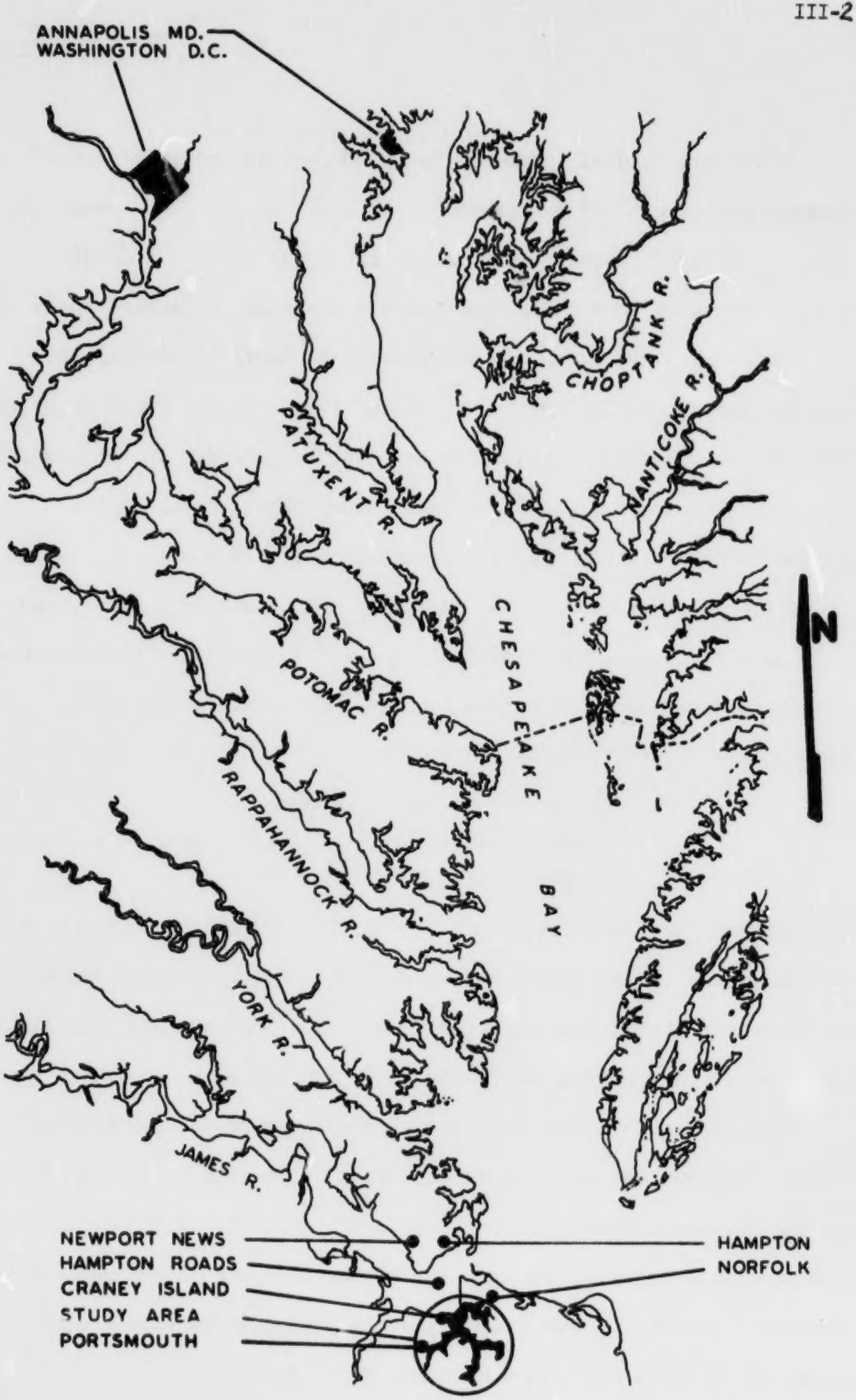

ANNAPOLIS MD.
WASHINGTON D.C.
PATUXENT R.
CHOPTANK R.
NANTICOKE R.
POTOMAC R.
CHESAPEAKE BAY
RAPPAHANNOCK R.
YORK R.
JAMES R.
N
NEWPORT NEWS
HAMPTON ROADS
CRANEY ISLAND
STUDY AREA
PORTSMOUTH
HAMPTON
NORFOLK

Figure 1

There are natural depths of 20 to 80 feet in the main part of Hampton Roads, but the harbor shoals to less than 10 feet toward the shores. Dredged channels lead to the principal ports. Federal project depth is 40 feet in the two main channels in Hampton Roads (15). One leads southward along the waterfronts of Norfolk, Portsmouth, and Chesapeake, following the Elizabeth River, and the other leads westward to the waterfront of Newport News at the entrance to the James River.

The climate throughout the James River Basin, of which the Elizabeth River is a part, is temperate, as determined by the latitude, prevailing westerly winds, the influence of the Atlantic Ocean, and its overall topography. The terrain is low-lying and flat with a maximum elevation of 25 feet, except for isolated sand dunes along beach areas (14). Average annual weather factors are:

Precipitation: 42.5 inches
Snowfall: 17 inches (about 1.7 inches of precipitation)
Temperature: 57°F

The eastern portion of the basin is sometimes subjected to the effects of hurricanes in the summer and early fall. Average annual temperature is generally higher near the ocean - 61.7°F. The average velocity of the wind is 8 to 10 MPH, but winds of 80 MPH may occur in storms (16).

The currents in this area are influenced considerably by the winds. The current velocity is 1.1 knots in Hampton Roads and .6 knots in the Elizabeth River (15). Tides in the vicinity of Craney Island (on the flats opposite the entrance of the Lafayette River which bisects Norfolk from east to west) are primarily semi-diurnal with a mean range of 2.6 feet and a spring range of 3.1 feet (14).

The Elizabeth River study area, a tributary of the James River just above the Hampton Roads Tunnel, is formed by three main branches; the Eastern Branch, the Western Branch, and the Southern Branch. Sampling stations are shown in Figure 4. A map indicating the location of the various sewage treatment plants in given in Figure 2. Municipal wastewater loadings for 1971 are presented in Table 1 and major industrial dischargers and associated average wastewater flows are given in Table 2 (52). In addition, the largest or most significant mass emission rates (lbs/day) are also given in Table 2. The inputs of the various industrial dischargers are graphically presented in Figure 3 (52). The three branches of the Elizabeth are characterized by heavy industrial, commercial and domestic facilities with their inherent problems. In addition to domestic waste discharged by primary sewage treatment plants and toxic wastes discharged by a variety of industrial concerns, the area is plagued by frequent oil spills and waste discharges from the extensive shipyard and docking facilities.

The Eastern Branch has shipbuilding and drydock facilities, an automobile assembly plant, an electric power plant, and several shipping docks which contribute to the waste input of the river. The Southern Branch, the most industrialized and longest branch of the Elizabeth River, is characterized by a variety of industrial and commercial concerns: cement plants, creosote treatment plants, shipbuilding and drydock facilities, food processing plants, power plants, chemical plants and U.S. Navy shipyards. On the Western Branch, the least industrialized branch of the Elizabeth River, are located a

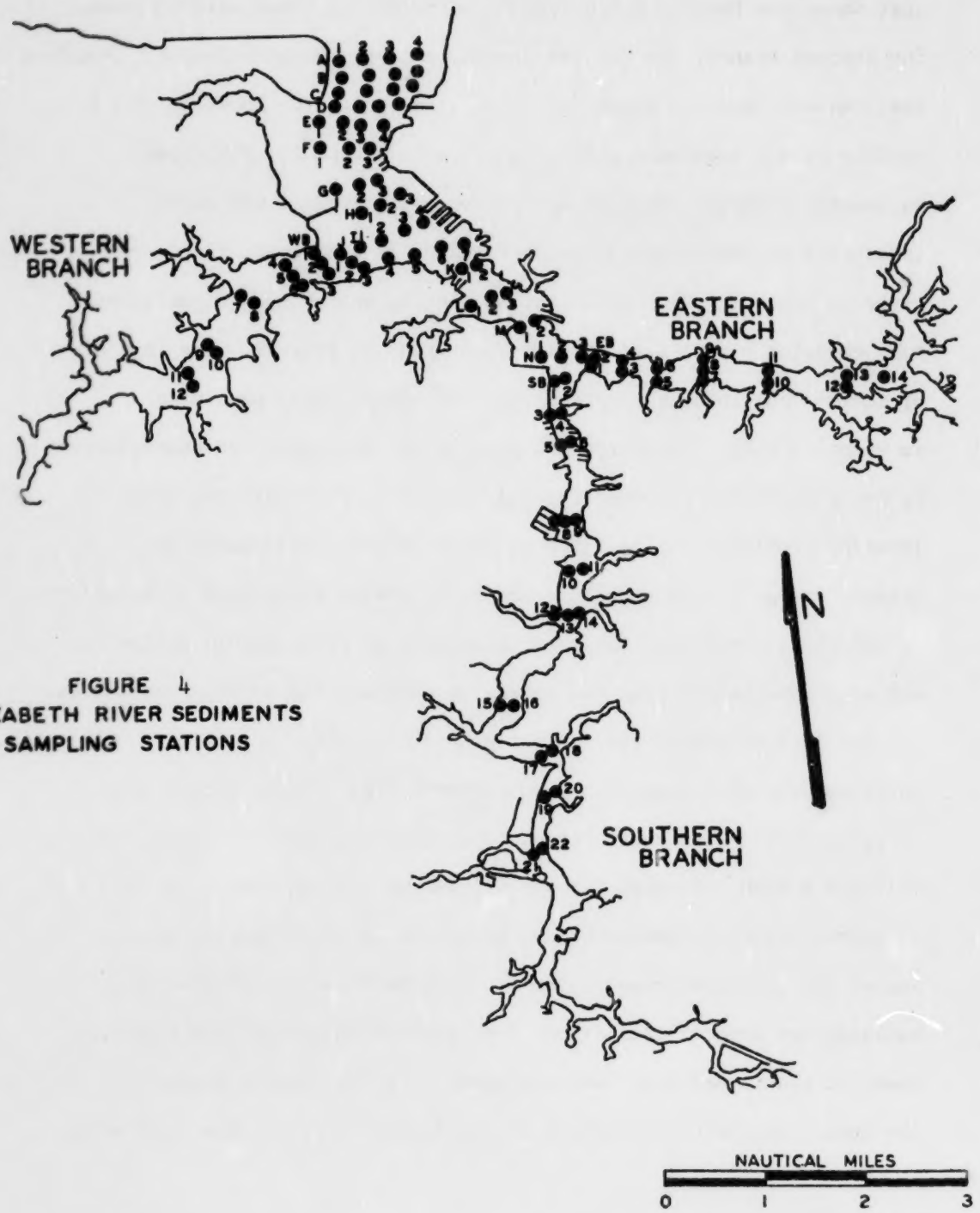


FIGURE 4
ELIZABETH RIVER SEDIMENTS
SAMPLING STATIONS

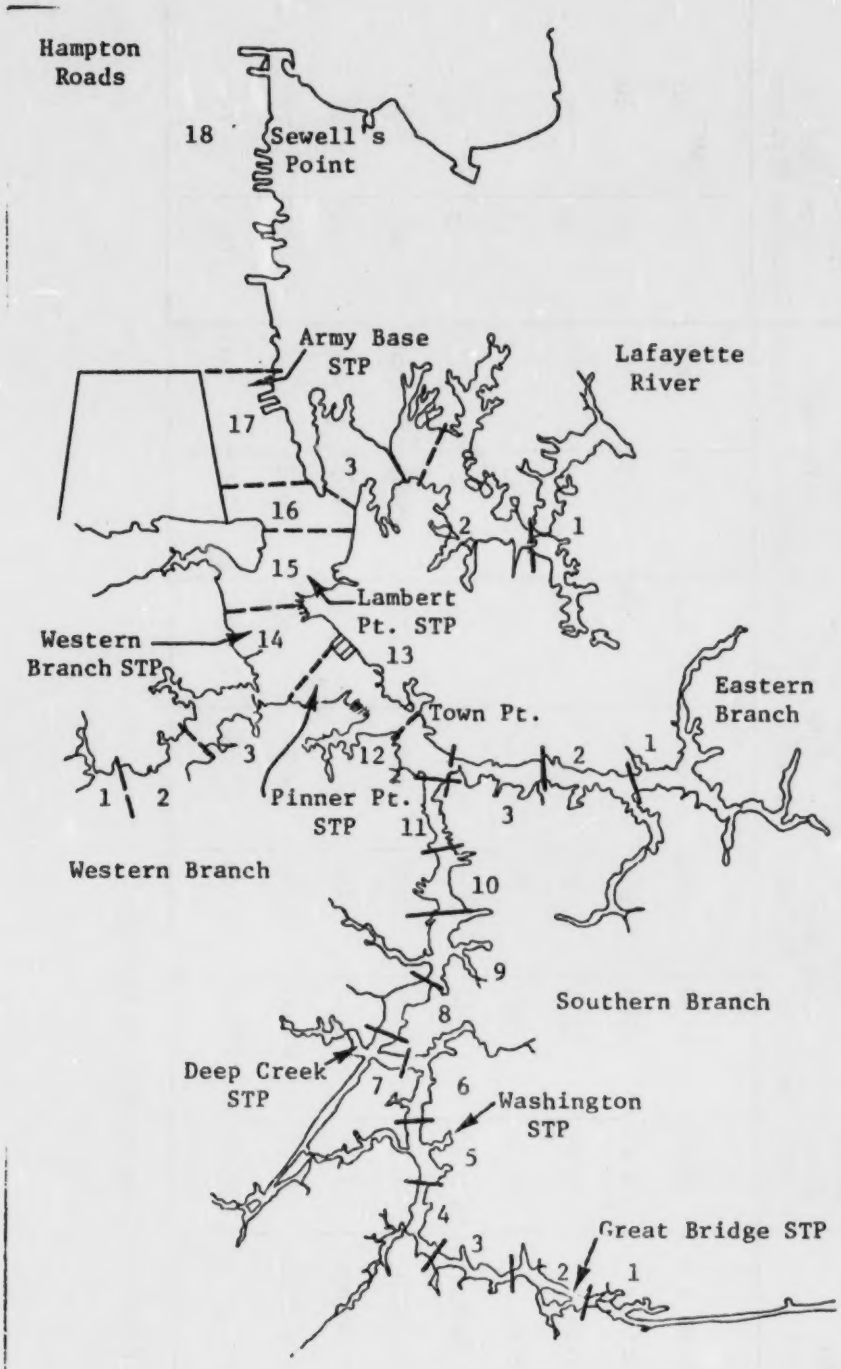


Figure 2 Sewage Treatment Plant Locations (44)

TABLE 1

Municipal Wastewater Loadings - 1971 (49)

Facility Name	Average Daily Flow (MGD)	BOD (lbs/day)		Total Sus. Solids (lbs/day)		NH_3-N (lbs/day)		Ortho-PO_4 (lbs/day)	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Carolanne Farms 1 & 2	0.53	1290	153	667	122	133	106	44	36
HRSD-Great Bridge	0.26	289	215	280	80	65	59	22	20
HRSD-Washington	0.87	1150	695	1070	416	218	196	72	65
HRSD-Deep Creek	0.42	520	87	410	129	21	17	35	28
Poplar Hill Subdivision	0.32	550	110	800	320	80	61	27	21
City of Portsmouth	11.92	18500	11600	22600	5220	2980	2680	989	894
HRSD-Western Branch	1.14	1540	931	1200	484	285	257	95	85
HRSD-Lambert's Point	28.93	45100	34000	39200	16600	7230	6510	2400	2170
HRSD-Army Base	12.99	17200	12500	14400	5700	3250	2920	1080	974

HRSD - Hampton Roads Sanitation District

TABLE 2

Industrial Discharges (52)

River Mi.	Industry	# Discharges	Avg. Wastewater Flow (gpd)	Largest or Most Significant Mass Emission Rate (lbs/day)
Main Br.				
0.4	Humble Oil and Refining		25,000	
3.0	Craney Island Fuel Facility		20,000	
4.4	Virginia Chemicals Inc.	10	4,600,000	1,035,000 TS, 7,700 COD, 4,000 BOD, 515 TN, 55 Fl, 575 Al, 4 As, 138,000 SO_4, 12 Cd, 8.5 Cr, 1.7 Pb, .074 Hg, 3.34 Ni, 86 Zn
4.7	Norfolk and Western Railroad	1	68,000	
5.7	J.H. Miles & Co.	3	48,000	
6.4	Norfolk Coca-Cola Bottling Co.	3	38,000	
8.0	Norfolk Shipbuilding & Dry-docking	7	47,000	163 TS
8.4	U.S. Gypsum Co.		2,900	3.3 TS
8.8	Norfolk Naval Shipyard	8	46,169,760	
8.9	Gulf Oil Co.		10,000	2 BOD, 3 O&G, 2 TSS
9.0	Lone Star Industries		50,000	20 COD, 450 TS
9.1	F.S. Royster Co.	4		25,000 TS, 8.5 As, 292 Cd, 1,158 Fl
9.5	Atlantic Creosoting Co.	1	120,000	17,000 TS, 12,343 Cl, 1,900 SO_4
9.8	Cargill, Inc., Processing and Refining Div.			1,100 TS, 111 BOD, 157 SO_4, 323 Na
10.0	Allied Mills Feed Mill		196	4.4 TS
10.1	Portsmouth Paving Co.		60,000	68 O & G, 4522 TS
10.2	Texaco Oil Co.	1	40,000	550 Cl
10.3	Republic Creosoting Co.		155,000	226 COD, 15000Cl, 19000 TS, 517 SO_4, 35 SO_3

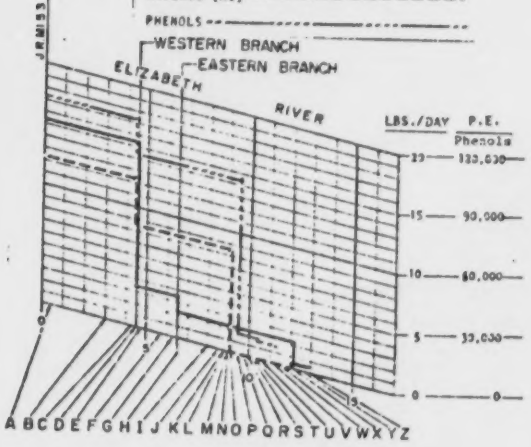
Table 2 Con't.

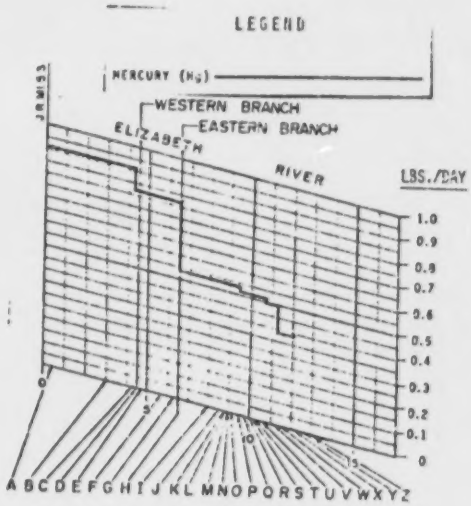
River Mi.	Industry	# Discharges	Avg. Wastewater Flow (gpd)	Largest or Most Significant Mass Emission Rate (lbs/day)
11.3	Eppinger & Russell	1	756,000	62000 Cl, 6800 SO_4, 81000 TS
11.5	Naval Weapons Station		3,950	
12.1	Swift Agriculture Chemicals Corp.	3	653,000	77000 TS, 965 COD, 92 O & G, 49 Fl, 1150 SO_4, 1.6 Cu, .38 Hg, .69 Ni, .68 Zn
12.6	Smith Douglas Fertilizer			47000 TS, 11000 COD
12.9	Weaver Fertilizer Co.		1,570,000	62 TN, 330 TP, 286000 TS, 2.0 Pb, 16500 TSS, 1600 Fl, 2.5 Cu, 2.0 Zn
13.3	Virginia Electric and Power Co.	6	1,030,000,000	43000 BOD, 1065000 COD, 30000 TN, 224000000 TS, 51.5 Cr
Eastern Branch				
0.7	Virginia Electric & Power Co.	7	206,000,000	43 Cr, 19 Zn
1.0	Norfolk Shipbuilding & Drydock	5	21,700	537 TS
1.1	Lone Star Industries		55,000	6700 TS, 79 SO_4
1.2	CPC Int'l. Div. of Best Foods	1	75,000	15 BOD, 271 TS
1.4	Norfolk Shipbuilding & Drydock	1	3,000	
2.1	H.B. Hunter Co., Inc.		80,000	
2.2	Ford Motor Co.	2	510,000	1740 COD, 1100 TS, 5.2 Fl, 3 Pb, 2 Ni
3.1	Chevron Asphalt Co.		96,000	
Western Branch				
0.0	Western Branch Diesel		16,000	
3.5	Norfolk Coca-Cola Bottling Co.		32,000	250 COD, 260 TS

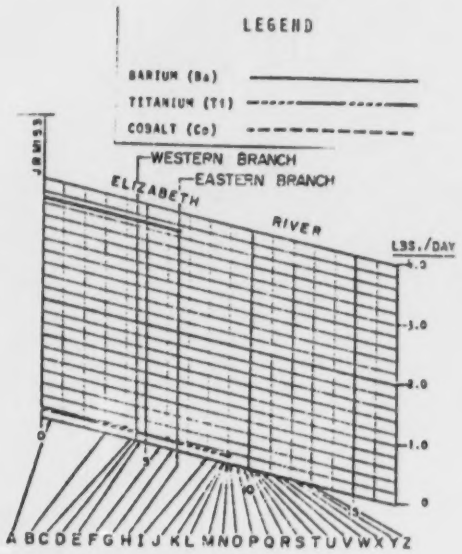
A HUMBLE OIL & REFINING CO.
B USN-CRANEY IS. FUEL FAC.
C VIRGINIA CHEMICALS INC.
D NORFOLK COCA COLA
D WESTERN BRANCH DIESEL
E N & W. R.R.
F J.H. MILES & CO.
G NORFOLK COCA COLA
H CHEVRON ASPHALT CO.
H FORD MOTOR CO.
H H.B. HUNTER CO.
H SOUTHERN/NORFOLK S.B. & D.D.
H CPC INTERNATIONAL
H LONE STAR IND
H BRAMBLETON/NORFOLK S.B.& D.D.
I BERKELEY/NORFOLK S.B. & D.D.
J U.S. GYPSUM CO.
K NORFOLK NAVAL SHIPYARD
L PROCTOR & GAMBLE
M GULF OIL CO.
N LONE STAR IND
O F.S. ROYSTER, CO.
P ATLANTIC CREOSOTING CO.
Q CARGILL, INC
R ALLIED FEED MILLS
S PORTSMOUTH PAVING
T TEXACO INC
U REPUBLIC CREOSOTING CO
V EPPINGER & RUSSELL CO
W USN-WEAPONS STATION
X SWIFT CHEMICALS
Y SMITH-DOUGLAS CHEMICAL
Z WEAVER FERTILIZER CO

Figure 3
Industrial Discharges
(52)

NOTES
CUMULATIVE DISCHARGES DO NOT INCLUDE THOSE OF VEPCO
NO DISCHARGE CONSTITUENCY DATA AVAILABLE FOR MILITARY INSTALLATIONS
P.E. = POPULATION EQUIVALENT
HORIZONTAL SCALES IN STATUTE MILES FROM RIVER MOUTHS







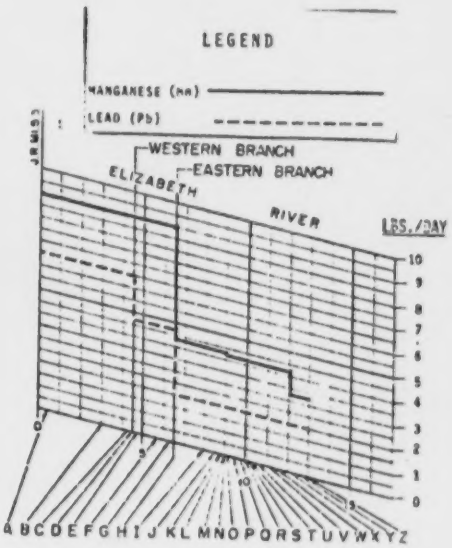
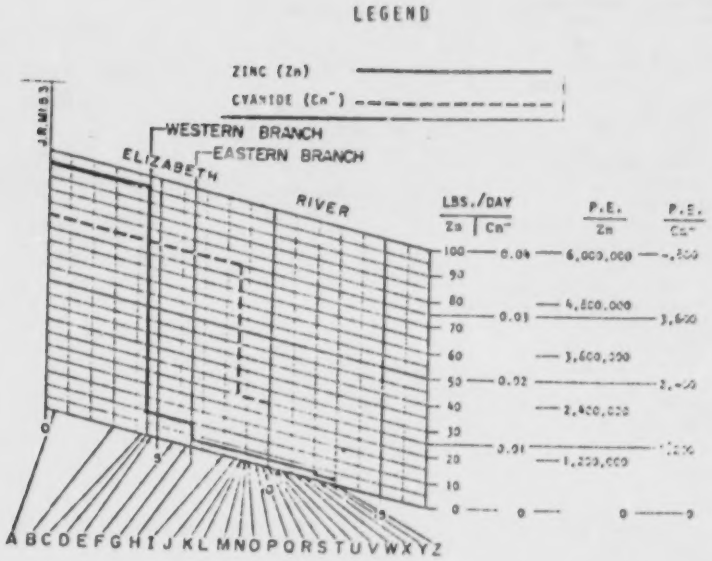
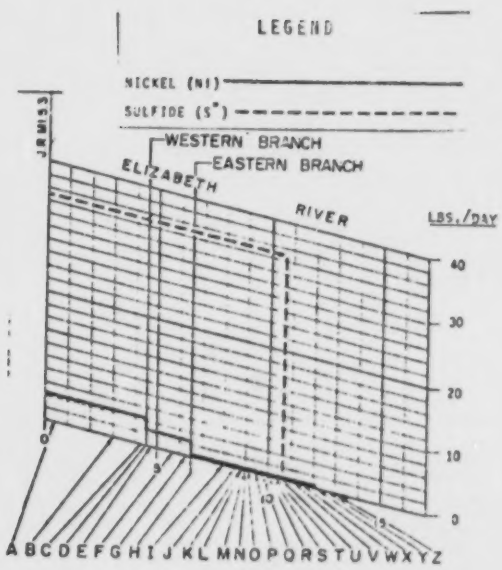
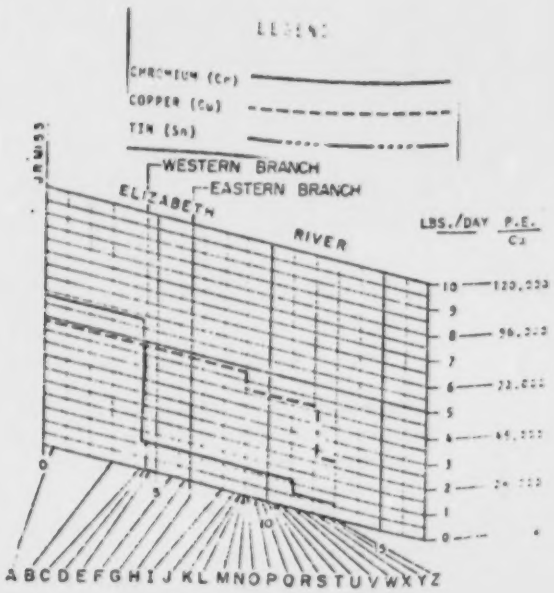


Figure 3 Con't.







chemical manufacturing plant and shipyards. The Main Branch houses shipping terminals, coal loading yards, an oil terminal, and sewage treatment plants (2). The navigable portion of the three branches of the river is located within the boundaries of the cities of Portsmouth and Norfolk (1).

EXPERIMENTAL

Samples were taken with a Phelger corer. The top five centimeters representing substantial sediment-water interface were discarded and the sediment between five and fifteen centimeters was taken as the sample to be analyzed.

A portion of the well-mixed sediment was spread to dry at room temperature for 48 hours. After drying, the sample was pulverized using an agate mortar and pestle and again spread to dry for an additional 24-48 hours. A 1.0000 gram sample was placed in a 125 ml glass-stoppered erlenmeyer to which 25-50 ml of deionized-distilled water and 21.5 ml concentrated HNO_3 were added.[1] The samples were then heated at 48-50°C (17) for 4-6 hours in a shaking hot water bath. After digestion, the samples were cooled to room temperature and filtered through a 0.45 micron membrane filter and the volume adjusted to 100 mls. Blank solutions were run throughout the same extraction procedure (18, 19). This acid extraction procedure is believed to be 80 - 90 % efficient in the removal of sorbed and bound metals (40, 45, 54).

The filtered acid extracts were analyzed for Cd, Cr, Cu, Pb, Zn, Al and Fe, using a Varian Techtron AA-6 absorption spectrophotometer equipped with a standard pre-mix burner. Air and acetylene were used for all flame techniques, except for Al for which nitrous-oxide and acetylene were used. The flame stoichiometry was established

---

[1] Any volume between 20 and 25 mls can be used, the volume used here was delivered from a dispenser with a fixed volume delivery head that happened to deliver 21.5 mls. and was used for convenience sake.

as per manufacturers instructions for optimum working conditions. Standard operating parameters are shown in Table 3.

Mercury was analyzed using an automated flameless atomic absorption technique (20, 21, 22). Mercury analysis was performed by a cold vapor technique employing the Coleman Mercury Analyzer MAS-50 and a Technicon AutoAnalyzer. Concentrated sulfuric acid and potassium permanganate were added to oxidize the sample. Further oxidation of organomercury compounds was assured through the addition of potassium persulfate. Samples were then heated to 105°C in a closed system. Hydroxylamine sulfate-sodium chloride was used to reduce the excess permanganate. The mercury in the sample was then reduced to the elemental state through the addition of excess stannous sulfate and a large amount of air. The gaseous phase was then analyzed in the MAS-50.

Other paramteres used in the interpretation and examination of the metals results were determined as follows:

1. Water content - determined as per cent weight lost after samples were dried (18, 19);
2. COD - dichromate reflux (18, 19);
3. Total volatile solids - weight loss associated with ignition of sample in muffle furnace (18, 19);
4. Oil and grease - as hexane extractables (18, 19); and,
5. TKN - semi-automated phenolate method (18, 19).

In general, for all parameters including metals, precision of analysis was checked by duplication of 10 % or more of the samples.

TABLE 3
OPERATING PARAMETERS

Metal	Wavelength	Slit	Lamp Current	Flame	Stoichiometry
Cd	228.8	.5 nm	3 ma	AA	Oxidizing
Cr	357.9	.2	5	AA	Reducing
Cu	324.7	.5	3	AA	Oxidizing
Pb	217.0	1.0	5	AA	Oxidizing
Zn	213.9	.5	5	AA	Oxidizing
Al	309.3	.5	5	NA	Reducing
Fe	248.3	.2	5	AA	Oxidizing

AA - Air/Acetylene
NA - Nitrous Oxide/Acetylene

Accuracy was checked by periodically spiking samples and calculating % recovery.

RESULTS AND DISCUSSION

The purpose of this study was to assemble an up-to-date inventory of metals accumulation in the Elizabeth River. Ninety-six stations (Figure 2) were sampled in February of 1974 and the surfaces (5 - 15 cm) analyzed for Cd, Cu, Cr, Pb, Zn, Hg, Al and Fe.

The distribution of metals by geographical area is presented in Table 4. The average concentrations of Cr, Cd, Al and Fe were similar in all four divisions indicating that these metals are fairly evenly distributed throughout the entire area with some localized high spots. The Eastern Branch is highly contaminated with Cu, Pb, and Zn; the Southern and Western Branches also exhibit high levels of these metals. The Main Branch has somewhat less of all the metals analyzed, with localized high concentrations along its western side. The entire area is contaminated with Zn, Cr, and Cu but the concentrations in the Southern and Eastern Branches are greatest. High levels of Al and Fe found in the study area are normal estuarine concentrations and represent natural levels due to the relative abundance of both metals and the chemistry of the estuarine system. The remaining metals are expected to show the impact of man through waste discharges into the river. Figures 5 through 12 graphically depict the distribution pattern of metals in the Elizabeth River. Appendix I, Tables 5 through 12, lists the concentration of each metal found at the sampling stations. The concentrations for the remaining parameters are also listed in Appendix I, Tables 14, 16, 23, 24, 28 and 29.

The data has also been compiled as frequency distributions to illustrate the relative occurences for a given concentration range.

Table 4

GEOGRAPHICAL DISTRIBUTION OF METALS IN ELIZABETH RIVER

Metal	Main Branch	Eastern Branch	Western Branch	Southern Branch
Cadmium, mg/kg				
Low	< 1	< 1	< 1	< 1
Average	4.0-4.2	2.9-3.0	3.8-4.1	1.8-2.0
High	26	6	22	6
Chromium, mg/kg				
Low	9	17	19	10
Average	47	43	41	38
High	95	74	110	109
Copper, mg/kg				
Low	< 2	27	10	< 2
Average	36.6-36.7	140	70	74.8-74.9
High	246	221	233	395
Lead, mg/kg				
Low	< 3	35	< 3	< 3
Average	64.5-64.8	179	79.8-80.1	96.2-96.3
High	242	280	366	382
Zinc, mg/kg				
Low	65	73	80	38
Average	388	422	454	274
High	1690	841	2380	1016
Mercury, mg/kg				
Low	< .01	< .01	.10	< .01
Average	.10	.37	.24	.38
High	.65	2.73	.47	1.49
Aluminum, mg/kg				
Low	4790	9600	10960	3980
Average	13180	13539	15604	10656
High	17990	16980	17920	14290
Iron, mg/kg				
Low	10180	20560	21670	7970
Average	28749	26235	33524	26348
High	36840	35330	40440	37540

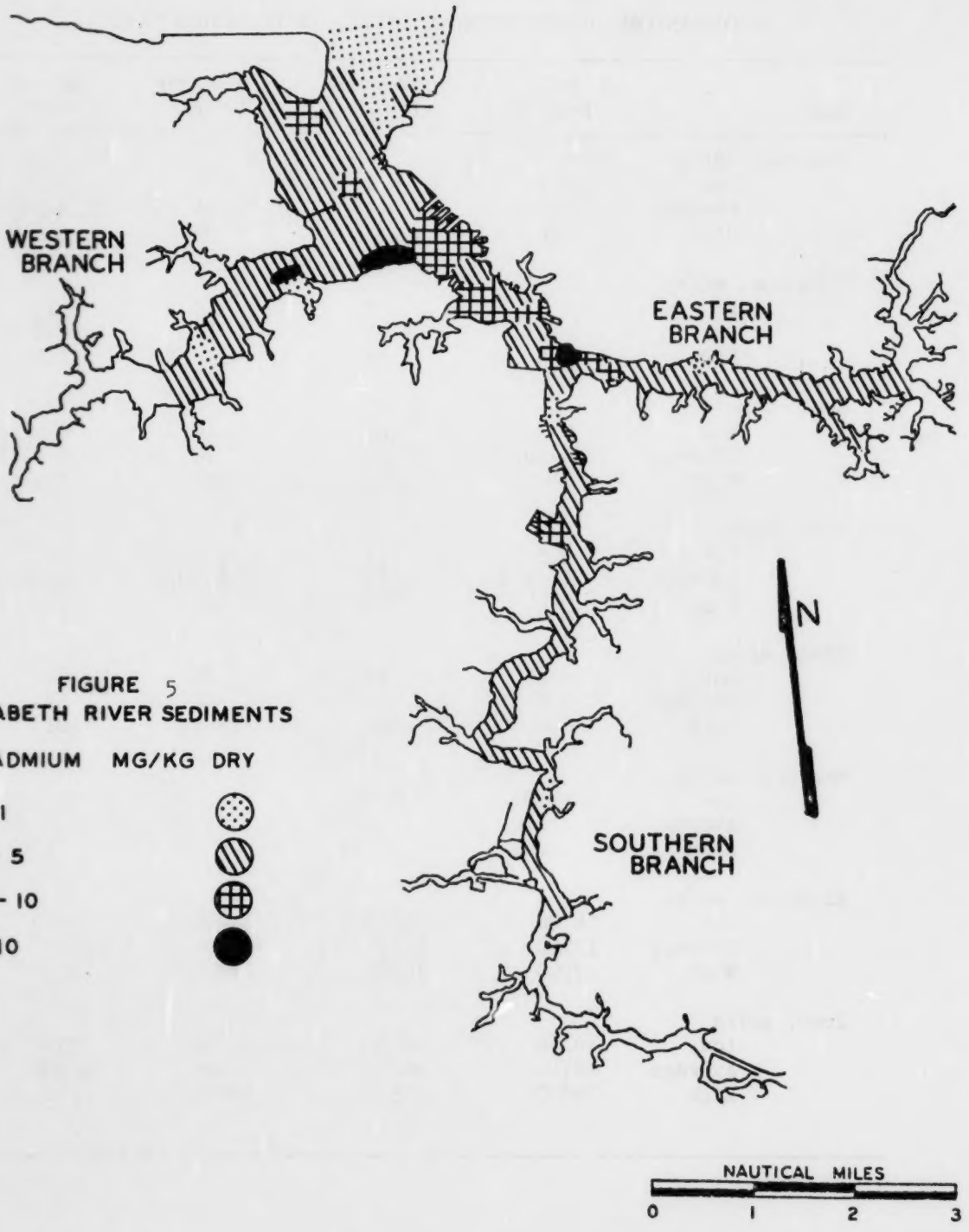


FIGURE 5
ELIZABETH RIVER SEDIMENTS

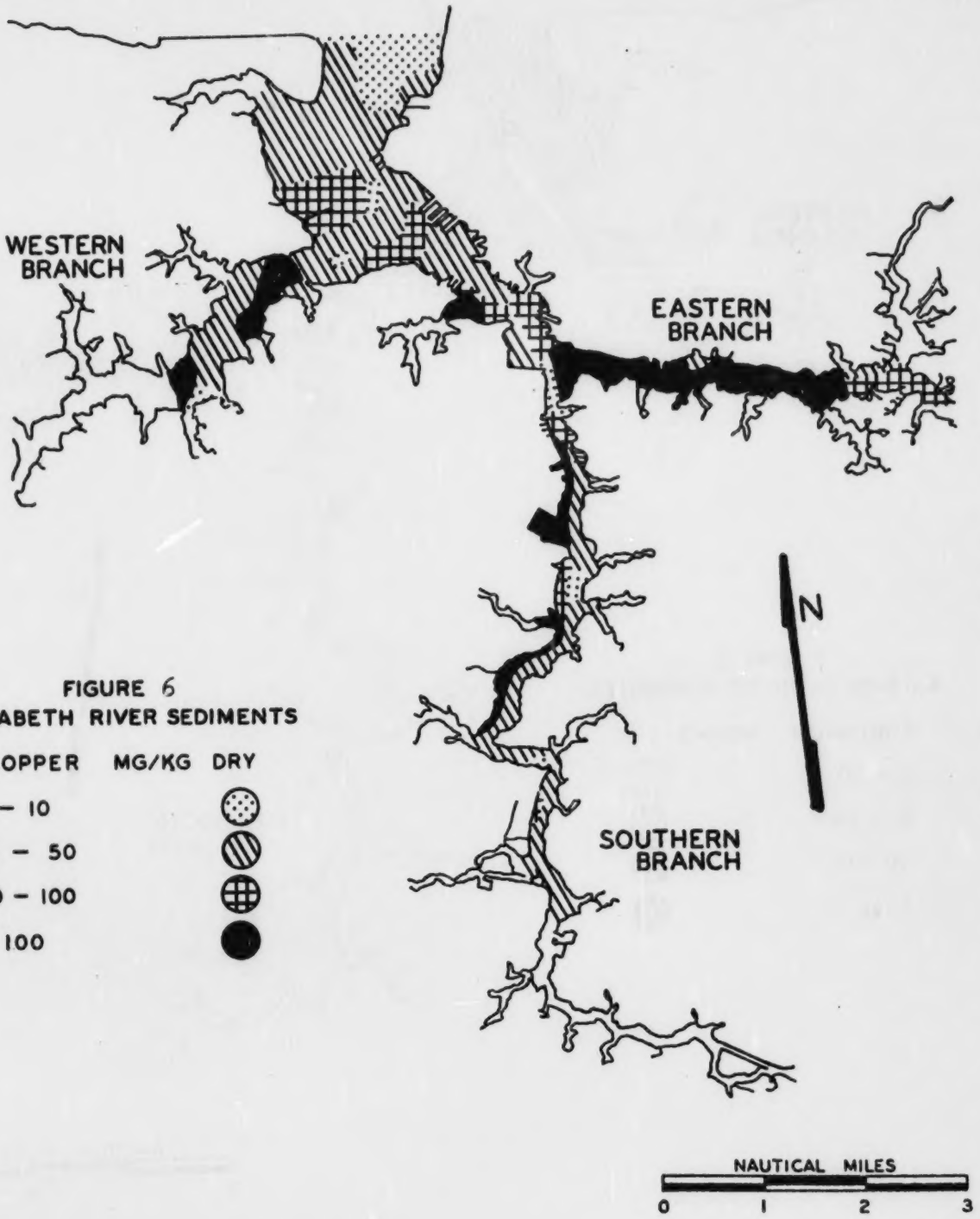


FIGURE 6
ELIZABETH RIVER SEDIMENTS

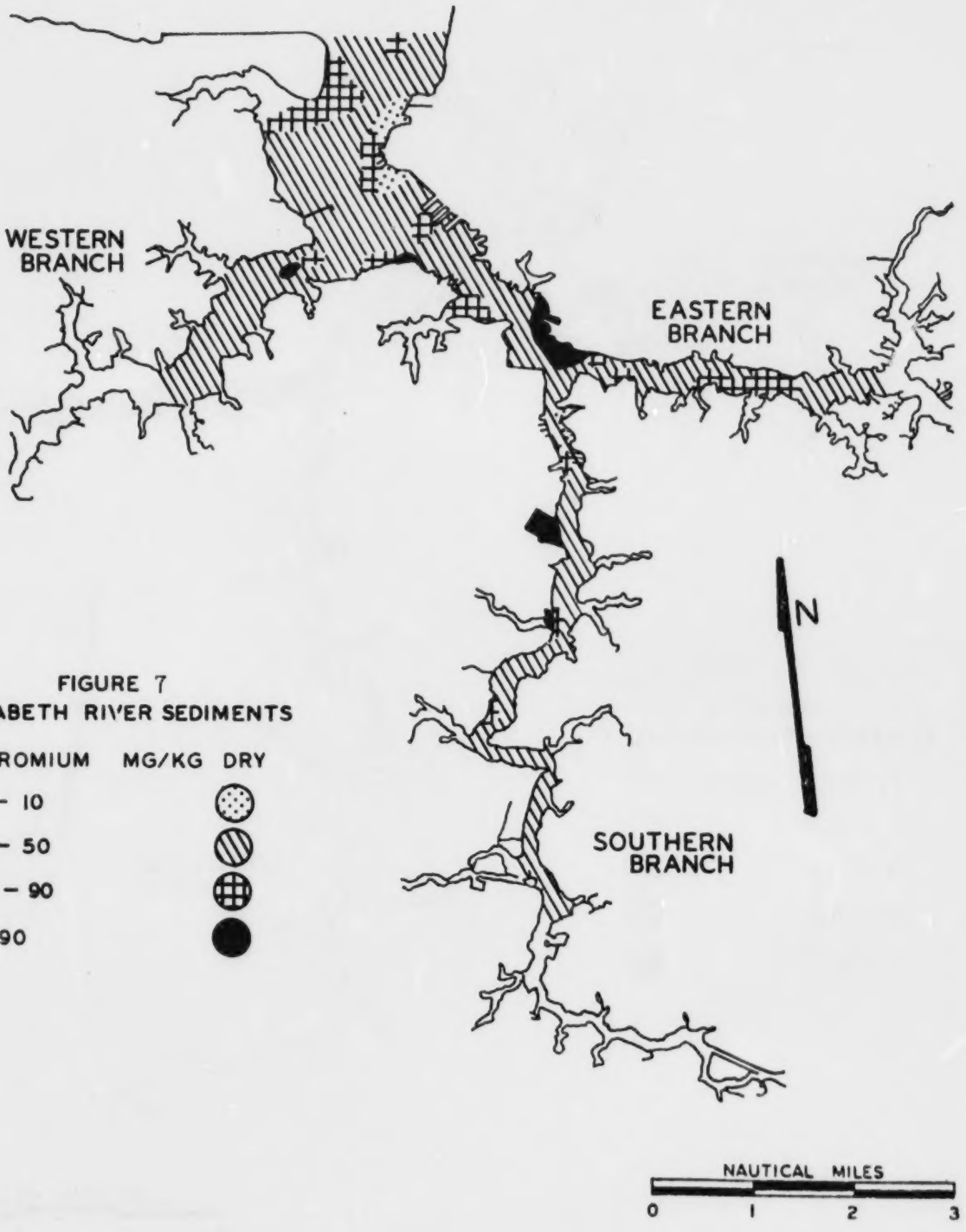


FIGURE 7
ELIZABETH RIVER SEDIMENTS

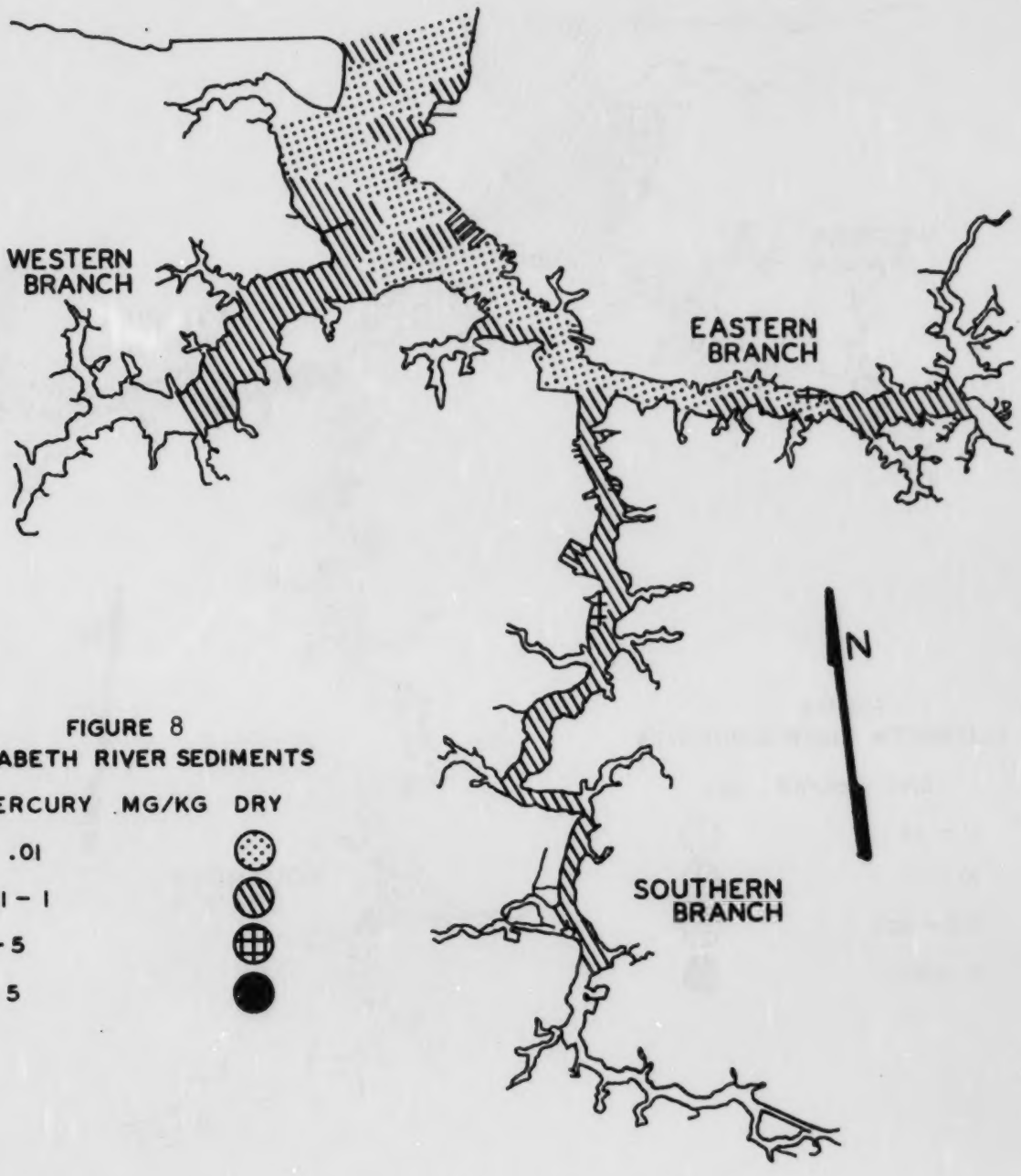


FIGURE 8
ELIZABETH RIVER SEDIMENTS

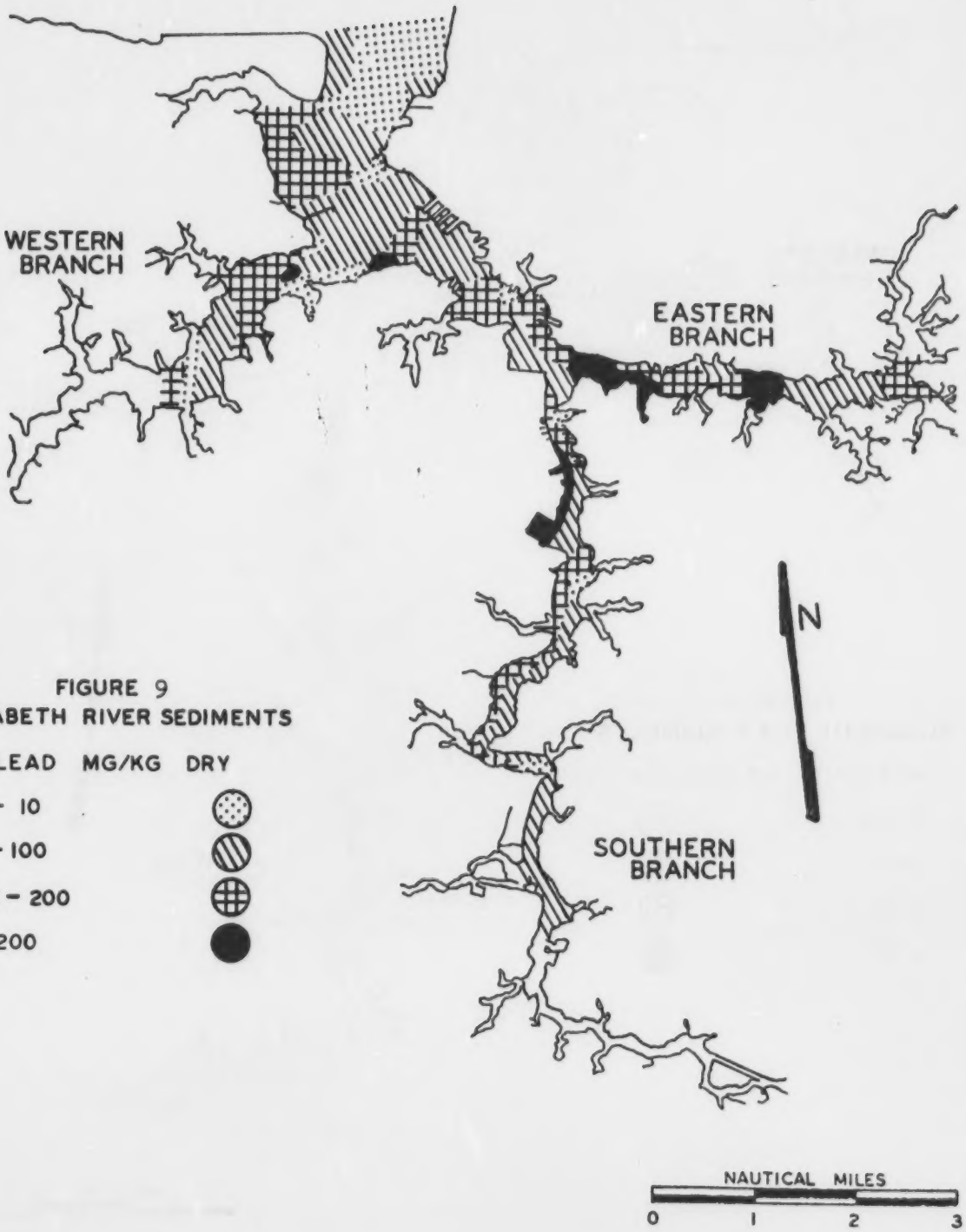


FIGURE 9
ELIZABETH RIVER SEDIMENTS

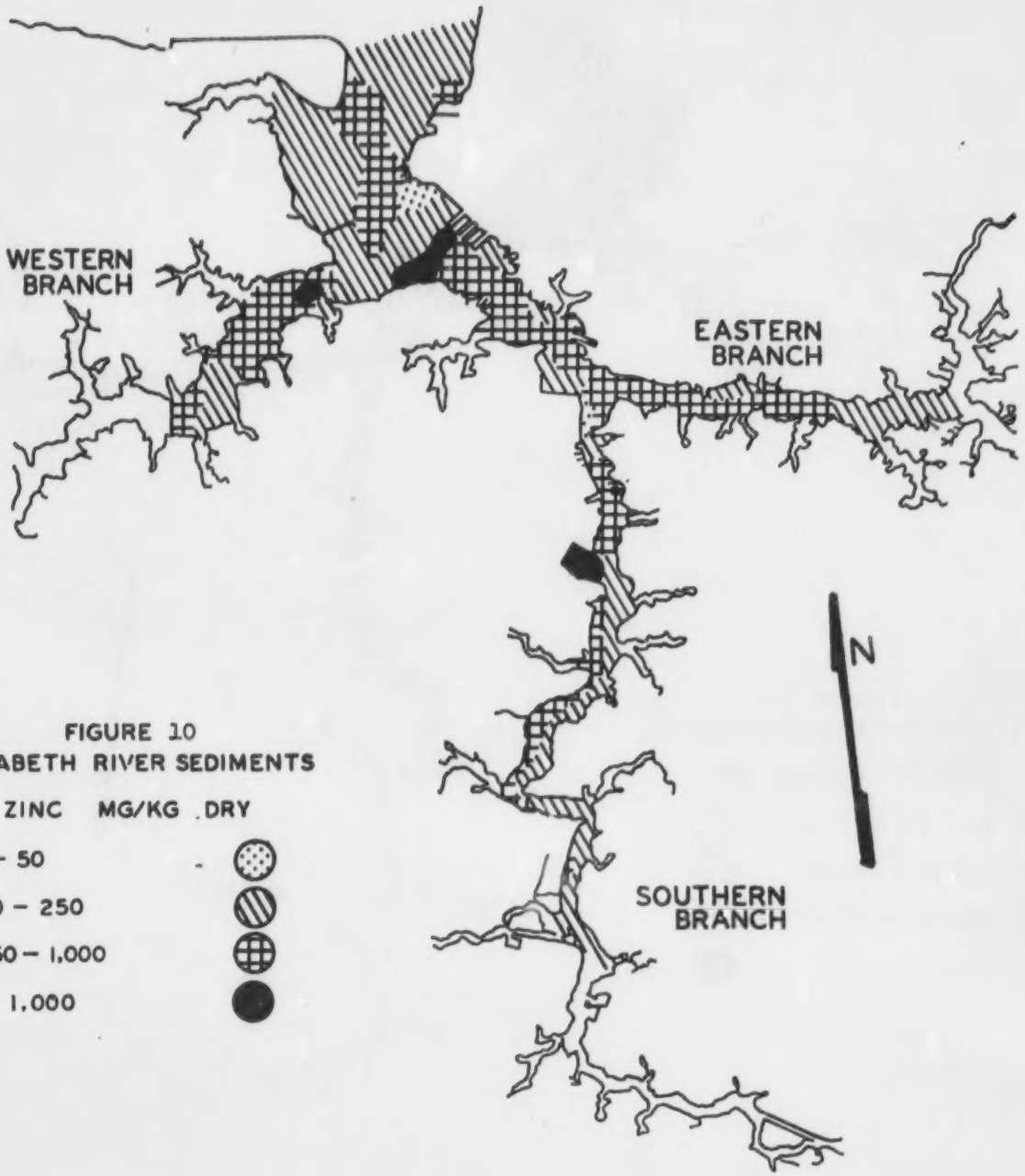


FIGURE 10
ELIZABETH RIVER SEDIMENTS

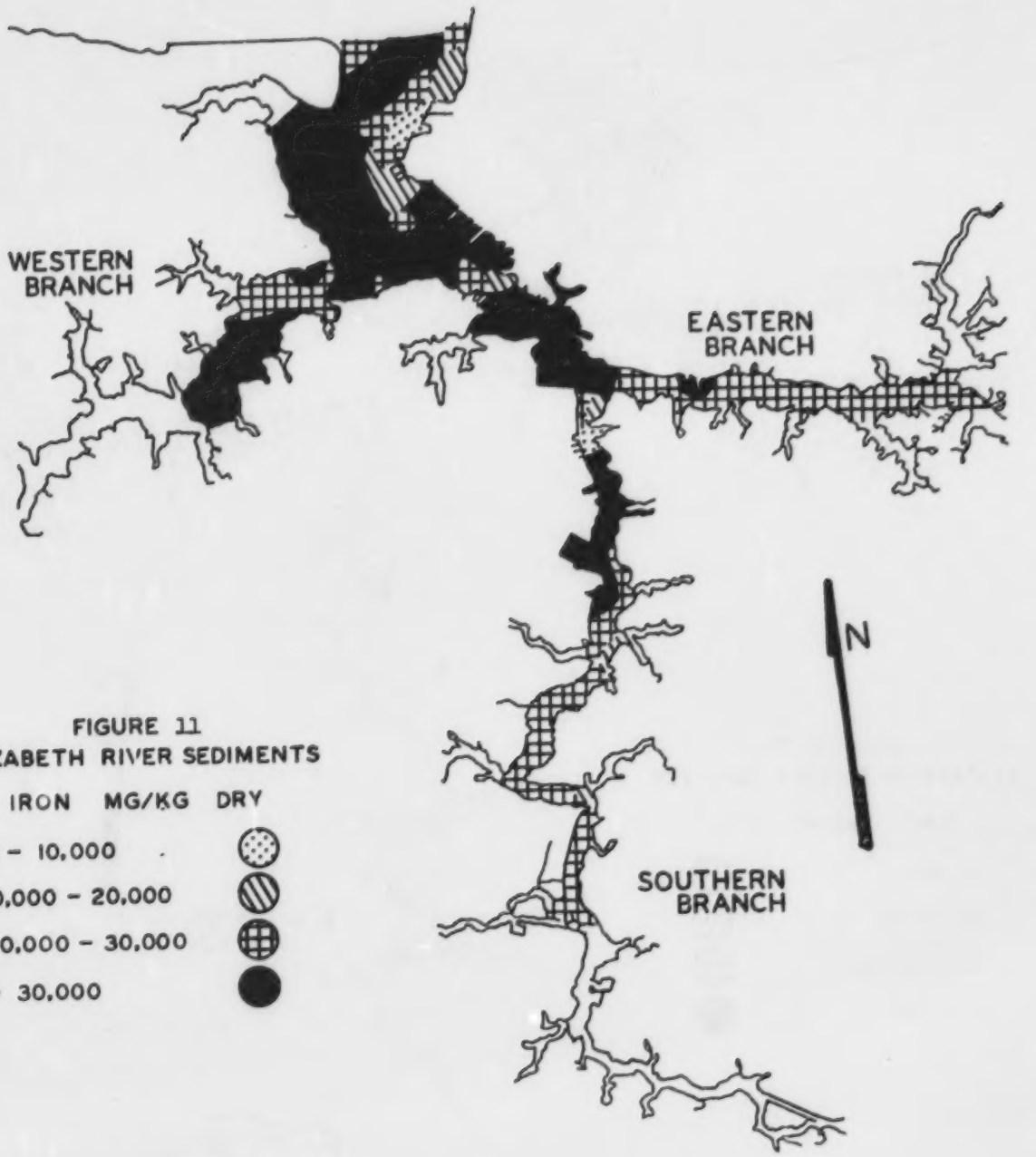


FIGURE 11
ELIZABETH RIVER SEDIMENTS

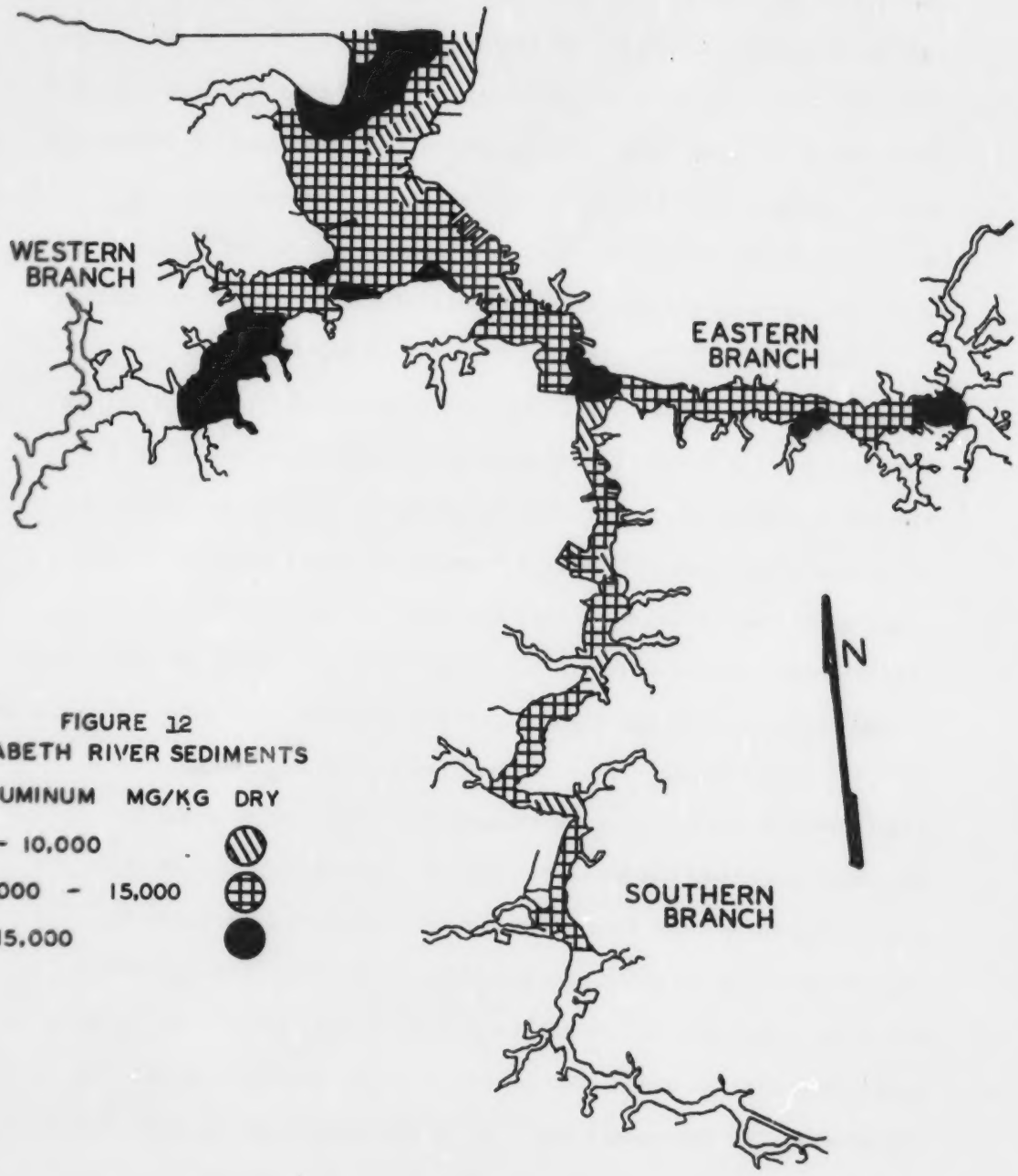


FIGURE 12
ELIZABETH RIVER SEDIMENTS

This information is presented in histogram form in Appendix II, Figures 13 through 20. It is interesting to note that all the metals exhibit frequency distribution patterns that are skewed to the right with the exception of Al and Fe which are skewed to the left. A skewness value, "k", has been calculated for each distribution (Table 13), and as expected only Al and Fe show negative skewness (37). As mentioned above, Al and Fe represent naturally occuring levels which may account for the different distribution which they exhibit.

This difference in distribution pattern may be of use in evaluating metal-sediment associations. Sommer (1974) has discussed the use of metal versus aluminum/metal concentration ratios as an aid for just this purpose (38). Aluminum was used as an indicator of clay mineral concentration in Sommers' Chesapeake Bay work since aluminum is associated with clay minerals in Bay sediments. The linear relationships found in his work for Cu and Al/Cu, Pb and Al/Pb, Cr and Al/Cr, and Mn and Al/Mn suggested that the metals were associated with the clay mineral portion of the sediment. Fe did not show a linear relationship. Sommers suggested sulfides as a possible alternate distribution mechanism for Fe. The occurences of high carbon concentrations also suggested the importance of possible organic matrices in which the metals might be held. The Elizabeth River data was examined in a like manner to see if the relationships exist in a similar manner for a highly industrialized estuary, as compared to the Chesapeake Bay. No linear relationships were found for any of the metals tested: Fe, Cr, Pb and Cu. Either Al is not

Table 13
"k" Values for Skewness

Metal	k
Fe	- 1.77
Hg	5.08
Al	- 0.82
Zn	2.36
Pb	1.19
Cu	1.79
Cr	0.60
Cd	3.41

associated with clay minerals in the Elizabeth River as it is in Bay sediments or non-linear relationships are indicative of man-made sources rather than naturally occuring levels. Metallic speciation may depend on the availability of anions such as sulfide or organic complexes which are not normally encountered in great abundance in non-industrial areas.

Changes in color from black to gray were noted in many of the core samples. An attempt was made to describe the color and texture of each sample as it was removed from the core for analysis. These descriptions are presented in Appendix III. Aside from the organic contribution to color, Biggs (23) and others (24, 25, 26, 27, 28, 29) have attributed the color of black sediments to hydrotrolite ($FeS \cdot nH_2O$), an amorphous ferrous sulfide. Black sediments will evolve H_2S when treated with acid if soluble sulfides are present, gray sediments evolve no H_2S. Sixteen (16) of the thirty (30) black sediments taken from the study area had "air" pockets which may have been H_2S and would indicate the presence of hydrotrolite. Van Straaten (26) found that the monosulfide (hydrotrolite) converts to the bisulfide (pyrite) with time. This conversion alters the color from black to gray. During the drying process the color of all samples that were black initially had changed to gray at the end of the drying period.

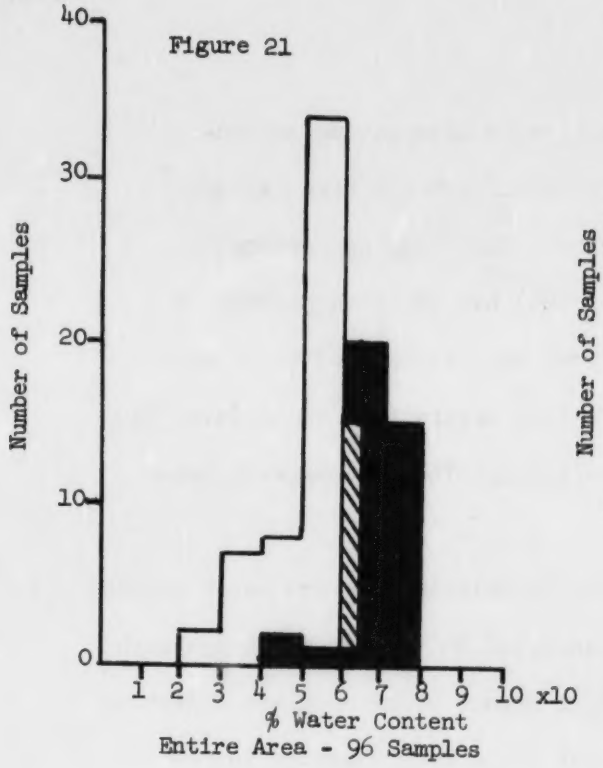
It has been suggested (23) that the ability of the hydrotrolite to precipitate is due to the condition of the overlying water: when there is no oxygen, hydrotrolite precipitates, and conversely, when the water oxygenated, it does not. The observed banding of black and

gray could be the result of deposition in alternating oxygen-deprived and oxygenated waters combined with the time dependent conversion of hydrotrolite to pyrite. This banding phenomenon was observed in 15 cores. Neilson (44) has observed periods of stratification in the Elizabeth River that would tend to produce periods with resultant oxygen deficient waters that would favor the formation of hydrotrolite and thus account for the observed color changes and banding.

Biggs (23) also found a marked correlation between water content and sediment color. The samples analyzed in this study showed such a relationship except in the Western Branch where no black sediments were found. The relationship is particularly pronounced in the Eastern and Southern Branches (Figures 21 through 24). The more separation that exists between the white and black areas on the graphs, the greater the correlation to water content; the striped area represents overlap. The actual water content at each station is presented in Appendix I, Table 14.

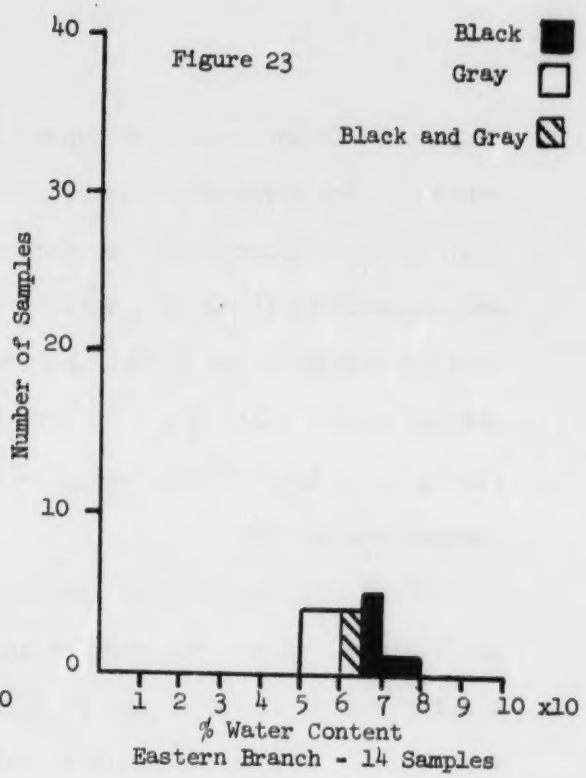
The suspected evolution of H_2S, the change in color from black to gray on drying, the banding phenomenon, and the correlation between water content and color certainly suggest the possible presence of hydrotrolite and, therefore, a "sulfide-precipitation" mechanism of metallic deposition in the Elizabeth River. Since the order of solubilities for divalent sulfides is $Hg < Cu < Pb < Cd < Ni < Zn$, Biggs (30) postulated that in black sediment the least soluble sulfides would show the highest ratio in the Elizabeth River relative

Figure 21



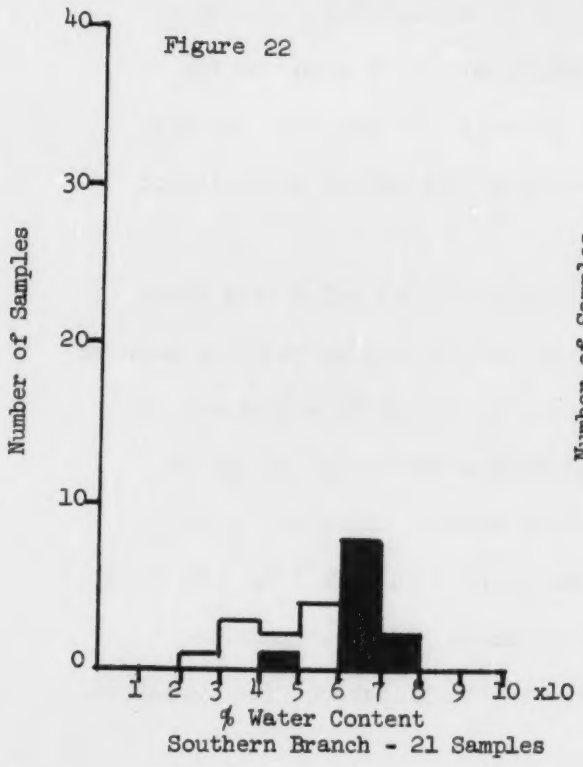
Entire Area - 96 Samples

Figure 23



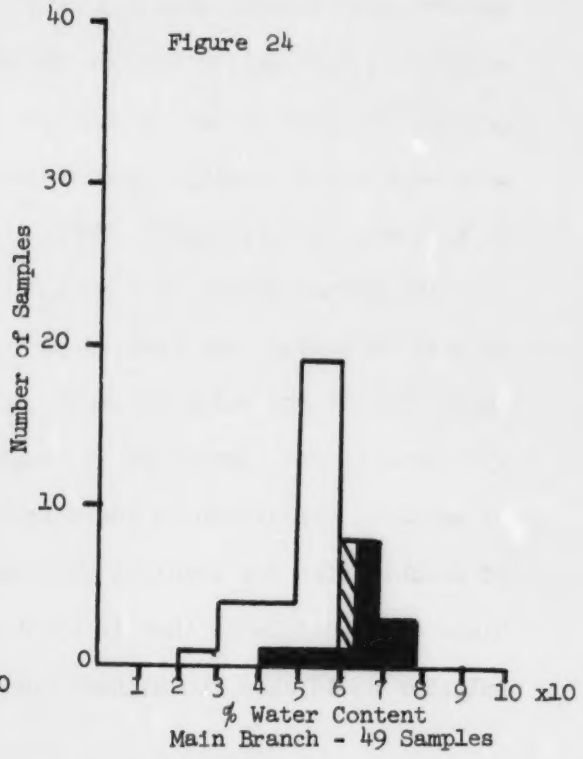
Eastern Branch - 14 Samples

Figure 22



Southern Branch - 21 Samples

Figure 24



Main Branch - 49 Samples

to their abundance in the Chesapeake Bay. If there is a greater concentration of the element in the Elizabeth River and if the sulfide is the least soluble chemical form which that element can be present as, then the elements should be present in the following ratio:

$$Hg > Cu > Pb > Cd > Ni > Zn$$

Table 15 shows the order of the ratios between the Elizabeth River and the Chesapeake Bay sediments.

Only one sample in the Main Branch exhibits the expected ratio, exclusive of Hg. One of the criteria given above was that the Elizabeth River value must exceed the Bay value in order for it to be used, since this is not the case with the Elizabeth River, the mercury values may be dropped from consideration. The metals in the Main Branch, then, probably exist in some form other than the sulfide. All six samples from the Eastern Branch follow the expected pattern. A similar situation exists in the Southern Branch: all but one sample conform to the pattern except for several inverted Zn and Cd values. In general the metals seem to exhibit the pattern given above and probably exist as sulfide in the Eastern and Southern Branches.

Using a technique developed by Ballinger and McKee (1971) to characterize bottom sediments using organic carbon and organic nitrogen data, the values from the Elizabeth River were tabulated (Appendix I, Table 23 - % TKN, Table 24 - % Organic Carbon). Organic nitrogen and organic carbon have been shown to correlate well with known sources and permit the classification of deposits into four general types (53). The four types are:

Table 15

Metals Concentration Ratios Between Elizabeth River and Chesapeake Bay Sediments

Station	Branch	Order of Decreasing Ratio
C-1	Main	Cu > Zn > Cd > Cr > Pb
D-1		Cu > Zn > Cd > Cr > Pb
D-2		Cu > Zn > Cd > Cr > Pb
E-1		Zn > Cu > Cd > Pb > Cr
F-2		Cu > Zn > Cd > Pb > Cr
F-3		Cu > Zn > Pb > Cd > Cr
G-2		Cu > Cd > Zn > Pb > Cr
H-3		Cu > Pb > Cd > Cr > Zn
I-4		Cu > Cd > Zn > Pb > Cr
J-5		Cd > Zn > Cu > Pb > Cr
M-2		Cu > Cd > Zn > Pb > Cr
N-2		Cu > Cd > Pb > Zn > Cr
N-3		Cu > Cd > Pb > Zn > Cr
EB-2	Eastern	Cu > Pb > Cd > Zn > Cr
EB-3		Cu > Pb > Zn > Cd > Cr
EB-4		Cu > Pb > Cd > Zn > Cr
EB-7		Cu > Pb > Zn > Cr > Cd
EB-8		Cu > Pb > Zn > Cr > Cd
EB-10		Cu > Pb > Zn > Cd > Cr
SB-5	Southern	Cu > Pb > Zn > Cd > Cr
SB-6		Cu > Zn > Pb > Cd > Cr
SB-7		Cu > Pb > Zn > Cd > Cr
SB-9		Cu > Pb > Zn > Cd > Cr
SB-10		Cu > Pb > Zn > Cd > Cr
SB-12		Cu > Pb > Zn > Cd > Cr
SB-13		Cu > Pb > Zn > Cd > Cr
SB-15		Cu > Pb > Cd > Cr > Zn
SB-18		Cu > Pb > Cd > Zn > Cr
SB-19		Cu > Pb > Zn > Cr > Cd
SB-20		Cu > Pb > Zn > Cd > Cr

I. Inorganic or aged, stabilized organic deposits;

II. High carbon, little N_2 contribution, slow O_2 demand;

III. Nitrogenous, substantial N_2 contribution, further stabilization likely, and;

IV. Actively decomposing sediments, high potential N_2 release and high O_2 demand.

Figure 25 shows the plotted Elizabeth River data. The type of bottom sediment associated with each station is presented in Table 26. The Main Branch is predominantly Types I and II; the Eastern Branch appears to have equal amounts of all four types; the Western Branch is predominantly Type I, as is the Southern Branch. It is interesting to note that the Western Branch had no Type IV sediments, which may explain the absence of black sediment noted earlier. The Western Branch has little industry and would appear to be relatively stabilized.

A further extension of this work is the product of organic nitrogen times organic carbon or OSI (Organic Sediment Index), which has been used to classify the bottom sediments into four categories which are:

I. OSI (0.0 - 0.48) - sand, clay, old stable sludge;

II. OSI (0.48 - 1.0) - organic detritus, peat, partially stabilized sludge;

III. OSI (1.0 - 5.0) - sewage sludge, decaying vegetation, pulp and paper wastes, sugar beet wastes, and;

IV. OSI (5.0 - > 10.0) - actively decomposing sludge, fresh sewage, matted algae, packinghouse wastes.

The numeric OSI values for the Elizabeth River are depicted graphically in Figure 26, and are presented by type of sediment in

Figure 25

BOTTOM SEDIMENT CLASSIFICATION

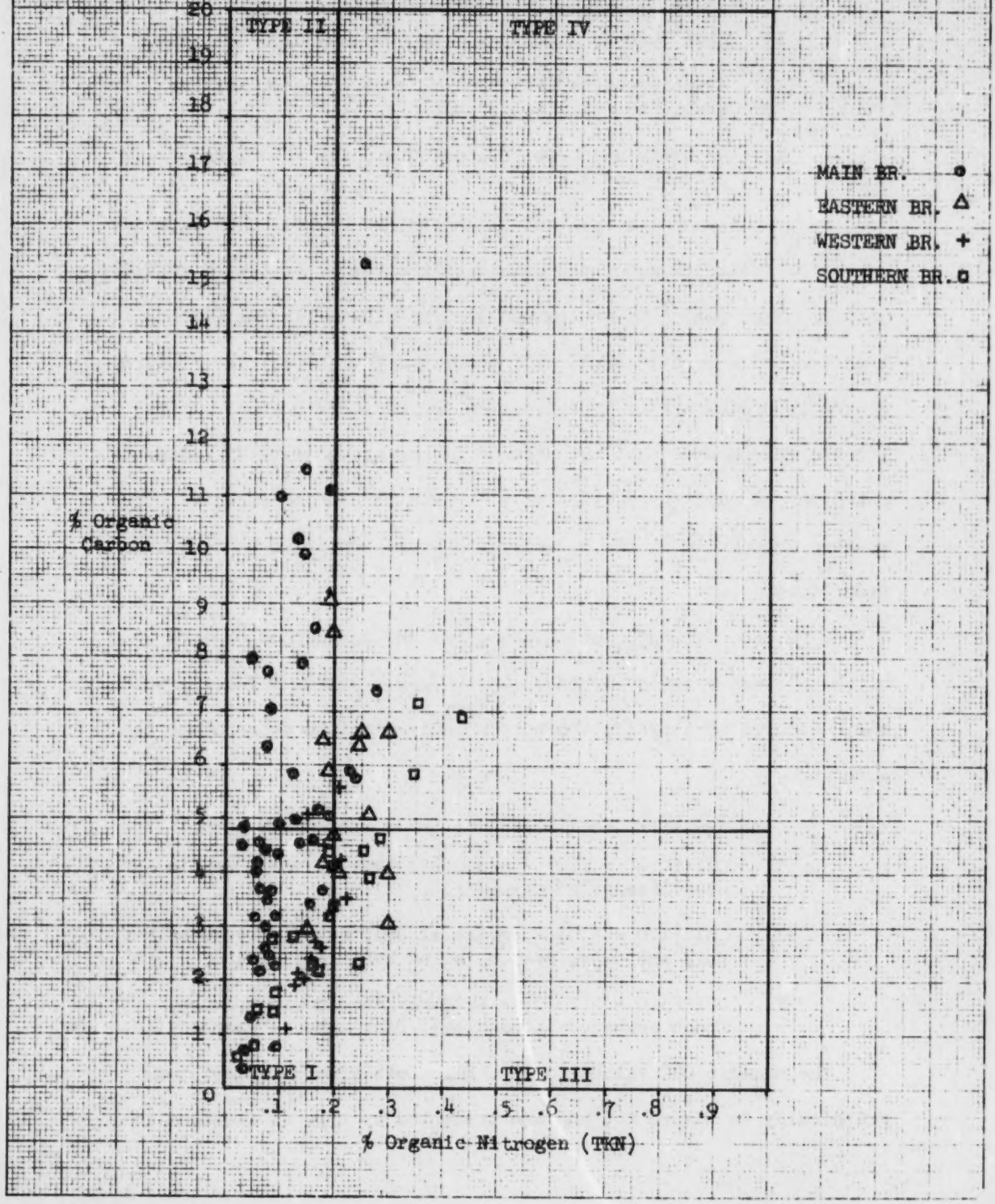


TABLE 26

BOTTOM SEDIMENT CLASSIFICATION

Location	Type	Location	Type	Location	Type
A 1	I	K 1	II	SB 1	I
2	I	2	I	2	I
3	I	L 1	II	3	I
4	I	2	II	4	I
B 1	II	3	I	5	III
2	II	M 1	I	6	I
3	I	2	II	7	IV
4	I	N 1	I	8	NS
C 1	II	2	IV	9	III
2	I	3	II	10	I
3	I	EB 1	II	11	I
4	I	2	IV	12	IV
D 1	IV	3	IV	13	I
2	III	4	II	14	I
3	I	5	III	15	III
4	I	6	II	16	I
E 1	II	7	I	17	I
2	I	8	IV	18	I
3	NS	9	I	19	III
4	I	10	IV	20	IV
F 1	I	11	IV	21	I
2	II	12	I	22	III
3	IV	13	III		
G 1	I	14	III		
2	II	WB 1	I		
3	I	2	I		
H 1	II	3	I		
2	I	4	I		
3	I	5	III		
I 1	I	6	I		
2	II	7	I		
3	I	8	II		
4	II	9	I		
J 1	I	10	II		
2	I	11	III		
3	II	12	I		
4	II				
5	II				
6	I				
7	I				

NS - No Sample

Figure 26

ORGANIC SEDIMENT INDEX

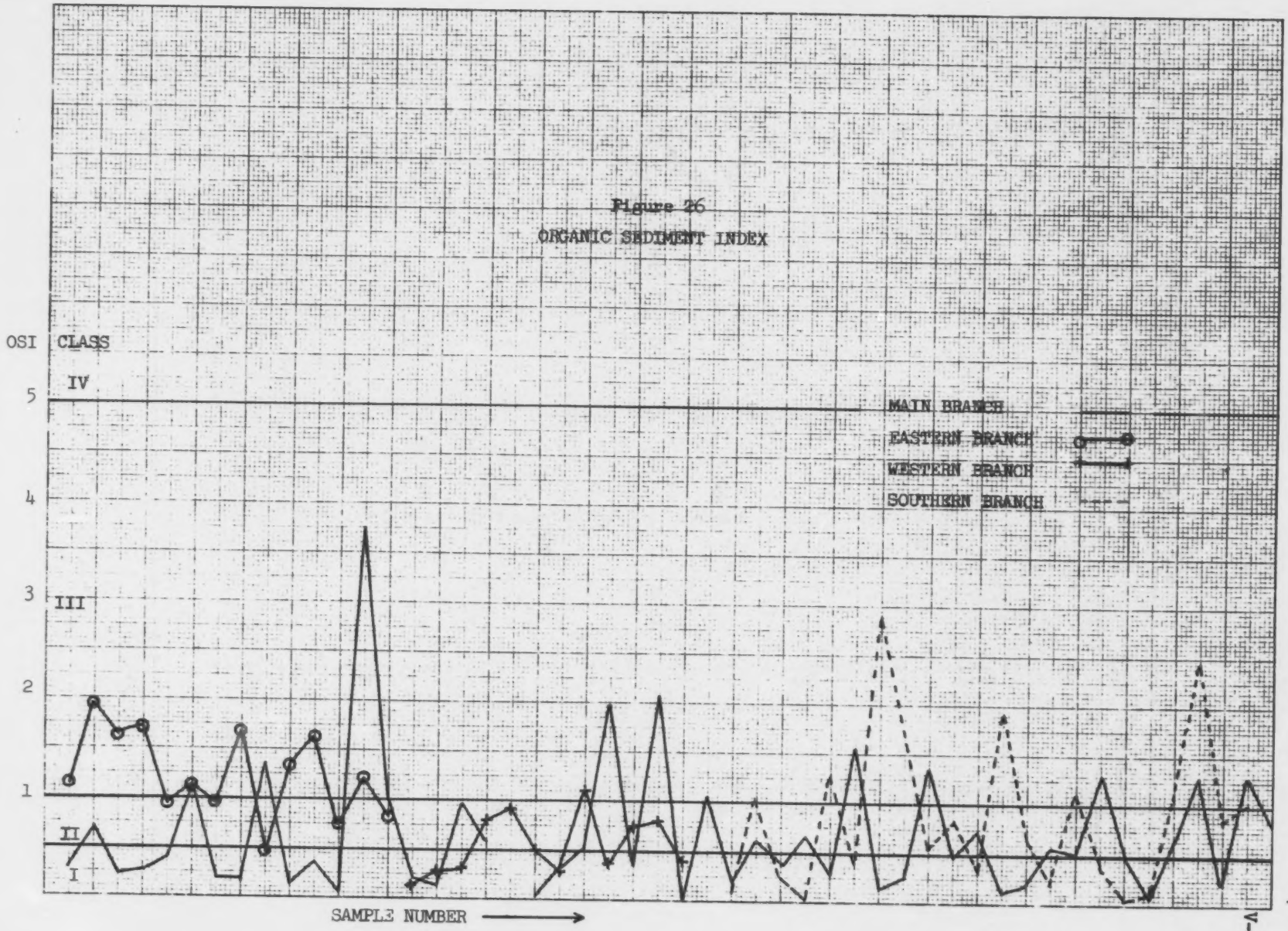


Table 27. It is interesting to note that the sharp peaks in Figure 26 (which represent high OSI values in Table 27) are in many cases at or near the location of a sewage treatment plant (by superimposing Figures 2 and 4, the following sampling stations are at or near STPs: D 1-4, E 1-4, G 1-3, J 1-7, and SB 15-22 - see Figure 27). As expected from the calculated OSI values, the bottom at these locations shows some impact from the presence of the sewage treatment plants.

The bottom sediment classification and OSI values are useful tools for examining the nature of the sediments from the Elizabeth River and have shown the possibility of an "organic matrix mechanism" of deposit and exchange, as an alternate or co-mechanism to sulfide precipitation and other forms of deposition and transport.

Another factor in evaluating the concentrations of metals in addition to their distribution and the form in which they may exist, is the particle size of the sediment. High surface area and adsorption capacity make clays a perfect scavenger for metallic substances. Given the absence of other contributing causes, particle size can be indicative of the metallic concentration of sediments (12). Before comparing one system to another, the particle size differences or similarities between the two should be accounted for so that particle size does not distort the interpretation of the data. No actual determination of particle size was possible in this study, however, the texture of each sample was recorded as the core was prepared for analysis. The sediments for the most part resembled those taken from

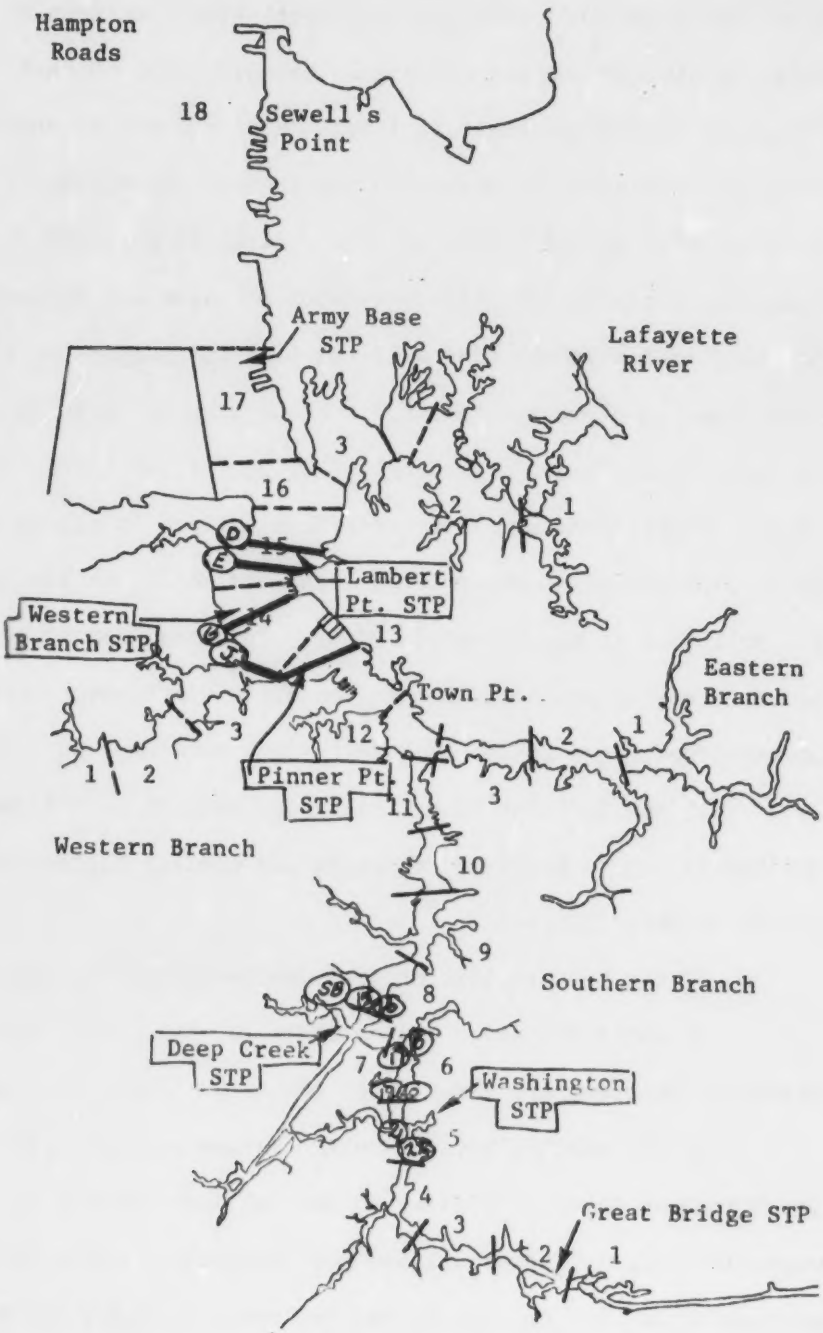
TABLE 27

OSI CLASSIFICATION

Location	Class	Location	Class	Location	Class
A 1	I	K 1	II	SB 1	I
2	II	2	II	2	I
3	I	L 1	III	3	I
4	I	2	II	4	I
B 1	I	3	I	5	III
2	III	M 1	II	6	I
3	I	2	III	7	III
4	I	N 1	I	8	NS
C 1	III	2	III	9	II
2	I	3	II	10	II
3	I	EB 1	III	11	I
4	I	2	III	12	III
D 1	III	3	III	13	II
2	III	4	III	14	I
3	I	5	II	15	III
4	I	6	III	16	I
E 1	II	7	II	17	I
2	II	8	III	18	I
3	NS	9	I	19	III
4	I	10	III	20	III
F 1	I	11	III	21	II
2	II	12	II	22	III
3	III	13	III		
G 1	I	14	II		
2	III	WB 1	I		
3	I	2	I		
H 1	III	3	I		
2	I	4	II		
3	II	5	II		
I 1	I	6	II		
2	II	7	I		
3	I	8	III		
4	III	9	I		
J 1	I	10	II		
2	I	11	II		
3	III	12	I		
4	I				
5	II				
6	I				
7	I				

NS - No Sample

Figure 27 Sampling Locations at or near STPs



the Baltimore Harbor in an earlier study (31), being of a silt or clay nature with no large sand particles or pebbles. In addition, Drifmeyer (1975) has indicated that Elizabeth River sediment is primarily a silt-clay complex and highly organic (45). Because the comparisons to follow are based on fairly large numbers of determinations that have been converted to overall averages for each system, it is felt that particle size is not likely to be a contributing factor in evaluating the distribution patters between one area and another.

Assuming that particle size will not bias the comparison of the Elizabeth River to other systems, (This assumption is based on 1) visual observations, 2) Drifmeyer's findings (45), 3) the averaging procedure used, and 4) comparisons are made between estuarines in fairly close geographic proximity.) an attempt has been made to define the degree of metallic pollution in the Elizabeth River. In attempting to evaluate the degree of metals contamination in the Elizabeth River, comparisons of concentrations found in the Elizabeth River were made to those found in:

1) the Patapsco River (Baltimore Harbor), a tributary of Chesapeake Bay in Maryland, representing another highly industrialized estuary (Table 17);

2) the open regions of the mid-Chesapeake Bay (Table 18);

3) other estuarine environments, in this case, the Delaware, Potomac, and James River estuaries (Table 19); and,

4) the earth's crust (average values at best) (Table 20).

The Elizabeth River is similar to the Baltimore Harbor in that it, too, supports a highly industrialized port facility. Table 17 provides a comparison of Cd, Cr, Cu, Pb, Zn and Hg levels in these two harbors.

Table 17

METALS IN ELIZABETH RIVER AND BALTIMORE HARBOR SEDIMENTS

Metal	Elizabeth River	Baltimore Harbor[1]
Copper, mg/kg		
Low	< 2	< 1
Average	65.1-65.2	342
High	395	2926
Lead, mg/kg		
Low	< 3	< 1
Average	91.0-91.2	341
High	382	13890
Zinc, mg/kg		
Low	38	31
Average	379.1	888
High	2380	6040
Cadmium, mg/kg		
Low	< 1	< 1
Average	3.3-3.5	6.3-6.6
High	26	654
Chromium, mg/kg		
Low	9	10
Average	44.4	492
High	110	5745
Mercury, mg/kg		
Low	< .01	< .01
Average	.22	1.17
High	2.73	12.20

[1]Villa, O. and P.G. Johnson, "Distribution of Metals in Baltimore Harbor Sediments," Environmental Protection Agency Region III Technical Report No. 59, Annapolis Field Office, (Jan. 1974).

Average Zn and Cd concentrations in Baltimore Harbor were twice the levels found in the Elizabeth River. Baltimore Harbor showed four, five and eleven times the concentrations of Pb, Cu and Cr, respectively, found in the Elizabeth River. For all the metals compared, Baltimore Harbor had considerably higher "high" values than the Elizabeth River.

Table 18 is a comparison of Elizabeth River values with those found in the open Chesapeake Bay (approximately five miles from the Magothy River, in mid-bay, to Cove Point). For all metals compared the average and "high" values found in the Elizabeth River exceeded the open Bay values. The Hg, Cd, Cr, Pb, and Zn were two to four times the average in the Bay; while the average Cu value was ten times the Bay value.

The Delaware, Potomac and James estuaries provide additional opportunities to evaluate the Elizabeth River data. While none of these three estuaries have the concentrated industrial complex to the extent that Baltimore Harbor and the Elizabeth River do, they provide for comparisons primarily with an industrialized tidal system (Delaware), an estuary with mainly municipal inputs (Potomac), and a third system with a lesser degree of both municipal and industrial inputs (James). The James River, being physically adjacent to the Elizabeth River, provides an interesting contrast: the sediments of the James contain the least amount of Zn and Pb, and in fact, the average values of the James (Table 19) are similar to the Bay values (Table 18). Potomac estuary sediments exhibit greater ranges of values than the James but are no more than two times greater than Bay concentrations.

Table 18

METALS IN ELIZABETH RIVER AND CHESAPEAKE BAY SEDIMENTS

Metal	Elizabeth River	Chesapeake Bay[1]
Copper, mg/kg		
Low	< 2	< 1
Average	65.1-65.2	6.4-7.0
High	395	22
Lead, mg/kg		
Low	< 3	9
Average	91.0-91.2	27
High	382	86
Zinc, mg/kg		
Low	38	33
Average	379	128
High	2380	312
Cadmium, mg/kg		
Low	< 1	< 1
Average	3.3-3.5	< 1
High	26	< 1
Chromium, mg/kg		
Low	9	18
Average	44	25
High	110	42
Mercury, mg/kg		
Low	< .01	< .01
Average	.22	.061-.067
High	2.73	.31

[1]Annapolis Field Office, unpublished, 1972-1973

Table 19

METALS IN ELIZABETH RIVER, DELAWARE RIVER, POTOMAC RIVER AND JAMES RIVER SEDIMENTS

Metal	Elizabeth River	Delaware River [1]	Potomac River [2]	James River [3]
Copper, mg/kg				
Low	< 2	4	10	NO
Average	65.1-65.2	73	--	--
High	395	201	60	DATA
Lead, mg/kg				
Low	< 3	26	20	4
Average	91.0-91.2	145	--	27
High	382	805	100	55
Zinc, mg/kg				
Low	38	137	125	10
Average	379	523	--	131
High	2380	1364	1000	708
Cadmium, mg/kg				
Low	< 1	< 1	< 1	NO
Average	3.3-3.5	2.9-3.1	--	--
High	26	17	.60	DATA
Chromium, mg/kg				
Low	9	8	20	NO
Average	44	58	--	--
High	110	172	80	DATA
Mercury, mg/kg				
Low	< .01	< .01	.01	.02
Average	.22	1.99	--	.32
High	2.73	6.97	.03	1.00

[1] Annapolis Field Office, unpublished, 1972-1973.

[2] Houser, M.E., and M.I. Fauth, "Potomac River Sediment Study," Naval Ordnance Station, Indian Head, Maryland (1972).

[3] Pheiffer, T.H., et al., "Water Quality Conditions in the Cheaspeake Bay System," Environmental Protection Agency Region III Technical Report No. 55, Annapolis Field Office (August 1972).

The Delaware estuary shows consistently higher levels than the James or Potomac and is quite similar to the Elizabeth River values.

Table 20 shows average concentrations of heavy metals in the earth's crust. As can be seen these concentration ranges are far less than those found in the Elizabeth River. Those values from the Chesapeake Bay and the James River are just slightly higher than the values in Table 20. For the Potomac sediments, Pb, Zn and Cd are in excess of the averages, while Cr, Cu and Hg are within the specified ranges.

An inventory of existing metals concentrations in Elizabeth River sediments has been presented and evaluated in terms of distribution. Factors such as sulfide precipitation and organic matrices and others have been addressed as possible mechanisms of transport and distribution.

Table 20

CONCENTRATION OF HEAVY METALS IN EARTH'S CRUST, AVG. RANGE[1,2]

Metal	Range, mg/kg
Chromium	.10 - 100.00
Copper	4.00 - 55.00
Lead	7.00 - 20.00
Zinc	16.00 - 95.00
Cadmium	.05 - 0.30
Nickel	2.00 - 75.00
Manganese	50.00 - 1100.00
Mercury	.03 - 0.40

[1]Bowen, H.J.M., Trace Elements in Biochemistry, Academic Press, N.Y. (1966).

[2]Green, J., "Geochemical Table of the Elements for 1959," Bulletin of the Geological Society of America, 70, pp. 1127-1184 (1959).

APPENDIX I

TABLE 5 CADMIUM ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	< 1	K 1	4	SB 1	1
2	< 1	2	4	2	2
3	< 1	L 1	7	3	< 1
4	< 1	2	6	4	< 1
B 1	< 1	3	2	5	4
2	< 1	M 1	3	6	3
3	< 1	2	9	7	6
4	< 1	N 1	3	8	NS
C 1	3	2	9	9	1
2	< 1	3	11	10	2
3	< 1	EB 1	4	11	1
4	< 1	2	6	12	4
D 1	4	3	6	13	4
2	3	4	5	14	1
3	< 1	5	4	15	4
4	1	6	4	16	1
E 1	7	7	1	17	2
2	1	8	1	18	< 1
3	NS	9	< 1	19	1
4	< 1	10	4	20	< 1
F 1	1	11	3	21	1
2	2	12	1	22	1
3	2	13	1		
G 1	1	14	1		
2	7	WB 1	2		
3	1	2	5		
H 1	4	3	1		
2	1	4	5		
3	1	5	22		
I 1	3	6	< 1		
2	4	7	2		
3	3	8	5		
4	10	9	< 1		
J 1	4	10	< 1		
2	3	11	3		
3	3	12	1		
4	23				
5	26				
6	9				
7	7				

NS - No Sample

TABLE 6 COPPER ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	13	K 1	32	SB 1	6
2	4	2	40	2	83
3	2	L 1	246	3	55
4	3	2	90	4	3
B 1	19	3	15	5	192
2	4	M 1	49	6	74
3	4	2	87	7	395
4	< 2	N 1	3	8	NS
C 1	40	2	112	9	30
2	3	3	128	10	91
3	< 2	EB 1	137	11	< 2
4	12	2	169	12	165
D 1	43	3	204	13	149
2	40	4	141	14	24
3	4	5	192	15	112
4	4	6	112	16	27
E 1	50	7	189	17	9
2	46	8	195	18	24
3	NS	9	27	19	96
4	13	10	221	20	52
F 1	24	11	198	21	27
2	28	12	74	22	32
3	47	13	30		
G 1	56	14	74		
2	65	WB 1	15		
3	3	2	32		
H 1	52	3	13		
2	7	4	212		
3	30	5	232		
I 1	13	6	18		
2	41	7	27		
3	43	8	130		
4	71	9	16		
J 1	18	10	18		
2	7	11	122		
3	11	12	10		
4	60				
5	66				
6	25				
7	22				

NS - No Sample

TABLE 7 CHROMIUM ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	39	K 1	48	SB 1	18
2	44	2	41	2	23
3	58	L 1	81	3	17
4	40	2	72	4	10
B 1	60	3	19	5	78
2	46	M 1	39	6	45
3	50	2	94	7	109
4	25	N 1	40	8	NS
C 1	75	2	95	9	30
2	45	3	95	10	48
3	29	EB 1	26	11	25
4	12	2	55	12	99
D 1	86	3	67	13	77
2	75	4	32	14	23
3	35	5	20	15	71
4	9	6	17	16	36
E 1	82	7	53	17	11
2	40	8	53	18	16
3	NS	9	30	19	43
4	10	10	74	20	24
F 1	39	11	73	21	13
2	23	12	27	22	26
3	51	13	41		
G 1	23	14	40		
2	82	WB 1	39		
3	9	2	51		
H 1	43	3	35		
2	25	4	19		
3	25	5	110		
I 1	40	6	32		
2	44	7	36		
3	32	8	40		
4	81	9	30		
J 1	32	10	35		
2	32	11	39		
3	26	12	31		
4	88				
5	92				
6	24				
7	20				

NS - No sample

TABLE 8 MERCURY ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	.60	K 1	< .01	SB 1	.07
2	.18	2	< .01	2	.33
3	< .01	L 1	.65	3	.15
4	< .01	2	< .01	4	< .01
B 1	< .01	3	< .01	5	.57
2	< .01	M 1	.33	6	.31
3	< .01	2	< .01	7	.94
4	< .01	N 1	< .01	8	NS
C 1	< .01	2	.23	9	.13
2	.41	3	< .01	10	1.49
3	< .01	EB 1	< .01	11	< .01
4	.10	2	< .01	12	.46
D 1	< .01	3	< .01	13	.52
2	< .01	4	< .01	14	.24
3	< .01	5	< .01	15	.52
4	< .01	6	< .01	16	.17
E 1	< .01	7	.13	17	< .01
2	.23	8	.43	18	.05
3	NS	9	< .01	19	.24
4	.15	10	< .01	20	.73
F 1	< .01	11	2.73	21	.22
2	< .01	12	.52	22	.80
3	< .01	13	.85		
G 1	.15	14	.43		
2	.60	WB 1	.10		
3	< .01	2	.25		
H 1	.15	3	.23		
2	< .01	4	.24		
3	< .01	5	.25		
I 1	< .01	6	.10		
2	.16	7	.45		
3	.30	8	.47		
4	.28	9	.23		
J 1	.15	10	.11		
2	.22	11	.30		
3	< .01	12	.11		
4	< .01				
5	< .01				
6	< .01				
7	< .01				

NS - No Sample

TABLE 9 LEAD ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	35	K 1	67	SB 1	41
2	3	2	64	2	92
3	2	L 1	194	3	102
4	3	2	162	4	< 3
B 1	41	3	< 3	5	382
2	3	M 1	100	6	108
3	< 3	2	162	7	344
4	< 3	N 1	13	8	NS
C 1	76	2	194	9	51
2	6	3	242	10	150
3	3	EB 1	275	11	6
4	32	2	251	12	184
D 1	9	3	242	13	165
2	8	4	188	14	60
3	6	5	280	15	114
4	10	6	181	16	51
E 1	153	7	183	17	3
2	67	8	169	18	29
3	NS	9	41	19	86
4	6	10	235	20	56
F 1	29	11	207	21	48
2	48	12	99	22	44
3	70	13	35		
G 1	130	14	118		
2	130	WB 1	10		
3	< 3	2	64		
H 1	86	3	< 3		
2	22	4	143		
3	60	5	366		
I 1	35	6	10		
2	80	7	35		
3	89	8	156		
4	156	9	6		
J 1	44	10	13		
2	16	11	145		
3	2	12	10		
4	226				
5	191				
6	35				
7	51				

NS - No Sample

TABLE 10 ZINC ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	249	K 1	440	SB 1	38
2	80	2	476	2	349
3	86	L 1	999	3	179
4	71	2	747	4	132
B 1	237	3	122	5	747
2	87	M 1	197	6	532
3	72	2	934	7	1016
4	53	N 1	80	8	NS
C 1	564	2	920	9	168
2	83	3	934	10	255
3	68	EB 1	456	11	60
4	271	2	674	12	665
D 1	541	3	841	13	507
2	455	4	402	14	122
3	120	5	289	15	337
4	155	6	240	16	120
E 1	961	7	402	17	54
2	427	8	377	18	80
3	NS	9	73	19	255
4	65	10	776	20	152
F 1	230	11	801	21	108
2	441	12	207	22	159
3	373	13	145		
G 1	198	14	230		
2	885	WB 1	94		
3	39	2	397		
H 1	367	3	91		
2	73	4	470		
3	107	5	2380		
I 1	212	6	105		
2	217	7	334		
3	186	8	841		
4	1023	9	103		
J 1	161	10	80		
2	87	11	467		
3	95	12	83		
4	1660				
5	1690				
6	314				
7	153				

NS - No Sample

TABLE 11 IRON ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	24020	K 1	27740	SB 1	27210
2	33460	2	18490	2	16120
3	35460	L 1	33750	3	10070
4	27390	2	33950	4	7970
B 1	33120	3	33560	5	33540
2	35520	M 1	33460	6	36540
3	36690	2	35900	7	37540
4	16240	N 1	33460	8	NS
C 1	34440	2	31010	9	25540
2	35960	3	31600	10	35140
3	28420	EB 1	26300	11	29250
4	11710	2	27430	12	29140
D 1	34390	3	30040	13	28530
2	35320	4	30430	14	18770
3	28520	5	27820	15	29620
4	10420	6	35330	16	27330
E 1	36840	7	29960	17	21500
2	27200	8	20560	18	13970
3	NS	9	28450	19	26070
4	10180	10	NSQ	20	27380
F 1	31940	11	28760	21	22220
2	17520	12	27440	22	23500
3	29910	13	29080		
G 1	31600	14	29890		
2	31060	WB 1	37740		
3	14630	2	21670		
H 1	33270	3	38440		
2	28770	4	26450		
3	30580	5	30190		
I 1	31850	6	29250		
2	35080	7	28350		
3	31600	8	38740		
4	33220	9	38540		
J 1	28670	10	35840		
2	34240	11	36640		
3	27200	12	40440		
4	30320				
5	35220				
6	22700				
7	31110				

NS - No Sample
NSQ- Not sufficient quantity

TABLE 12 ALUMINUM ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	10660	K 1	13930	SB 1	4750
2	16040	2	9880	2	6930
3	15900	L 1	14880	3	4740
4	13210	2	14360	4	3980
B 1	12450	3	13170	5	12380
2	15900	M 1	15250	6	10800
3	16090	2	17990	7	14290
4	7990	N 1	15710	8	NS
C 1	17420	2	16320	9	9980
2	16900	3	16340	10	12820
3	12120	EB 1	9600	11	10770
4	5170	2	13670	12	12930
D 1	16370	3	13180	13	12080
2	15710	4	13280	14	8120
3	10940	5	11480	15	13460
4	4790	6	13730	16	11460
E 1	17530	7	12250	17	8520
2	11290	8	13030	18	6710
3	NS	9	13760	19	13920
4	5800	10	16700	20	12790
F 1	14080	11	14640	21	11260
2	6790	12	13430	22	10440
3	13170	13	13820		
G 1	13120	14	16980		
2	13690	WB 1	16720		
3	6220	2	10960		
H 1	13670	3	16540		
2	12370	4	13530		
3	14160	5	14500		
I 1	13330	6	15390		
2	15030	7	13700		
3	12560	8	17010		
4	13040	9	16480		
J 1	11770	10	18030		
2	13870	11	17920		
3	13240	12	16470		
4	13470				
5	16730				
6	11460				
7	13830				

NS - No Sample

TABLE 14 WATER CONTENT ELIZABETH RIVER SEDIMENT STUDY

Location	% Wet Wt.	Location	% Wet Wt.	Location	% Wet Wt.
A 1	45.04	K 1	61.10	SB 1	37.20
2	58.89	2	49.50	2	56.00
3	55.05	L 1	63.80	3	31.50
4	51.29	2	58.60	4	21.40
B 1	56.06	3	50.10	5	66.80
2	54.30	M 1	62.30	6	65.10
3	53.00	2	70.20	7	70.00
4	39.40	N 1	49.80	8	NS
C 1	68.10	2	69.40	9	63.60
2	53.20	3	65.20	10	67.50
3	51.30	EB 1	56.60	11	52.30
4	32.30	2	68.70	12	71.80
D 1	71.90	3	68.40	13	68.40
2	68.00	4	66.60	14	48.90
3	46.30	5	55.90	15	70.40
4	30.80	6	61.50	16	58.90
E 1	69.40	7	66.60	17	39.20
2	56.00	8	64.40	18	47.60
3	NS	9	56.70	19	66.40
4	28.70	10	71.80	20	67.80
F 1	67.10	11	69.80	21	54.00
2	48.50	12	61.90	22	49.00
3	69.40	13	62.20		
G 1	57.60	14	59.80		
2	71.80	WB 1	47.30		
3	31.00	2	45.30		
H 1	64.50	3	49.80		
2	53.90	4	53.50		
3	55.20	5	59.00		
I 1	61.10	6	55.40		
2	63.80	7	55.20		
3	58.30	8	60.60		
4	66.60	9	54.00		
J 1	57.60	10	60.00		
2	60.70	11	60.50		
3	56.30	12	55.20		
4	58.40				
5	66.60				
6	52.30				
7	53.80				

NS - No sample

TABLE 16 COD ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	86440	K 1	187570	SB 1	36390
2	126080	2	91540	2	68040
3	98330	L 1	152900	3	74130
4	89960	2	129880	4	153000
B 1	210110	3	21160	5	122860
2	209910	M 1	98140	6	64610
3	69430	2	268260	7	310430
4	85580	N 1	61690	8	NS
C 1	225890	2	153790	9	61510
2	58730	3	136720	10	116950
3	62530	EB 1	173410	11	75350
4	38040	2	175690	12	158650
D 1	404880	3	175920	13	90440
2	119030	4	240720	14	51960
3	110580	5	82810	15	116300
4	64410	6	158180	16	61290
E 1	134970	7	126320	17	22720
2	121410	8	228200	18	38470
3	NS	9	80920	19	118510
4	18060	10	128320	20	190370
F 1	116520	11	172480	21	110230
2	206310	12	111550	22	10494
3	194540	13	106560		
G 1	107740	14	106790		
2	294540	WB 1	35650		
3	9970	2	56510		
H 1	209310	3	58470		
2	66530	4	123720		
3	86260	5	91540		
I 1	114500	6	73900		
2	134410	7	61340		
3	95850	8	152260		
4	303350	9	64040		
J 1	127730	10	138320		
2	120890	11	99490		
3	263500	12	70830		
4	168800				
5	155870				
6	120310				
7	107990				

NS - No Sample

TABLE 23 % Organic Carbon

Location	% Org. C	Location	% Org. C	Location	% Org. C
A 1	3.2	K 1	7.0	SB 1	1.4
2	4.6	2	3.4	2	2.5
3	3.7	L 1	5.7	3	2.8
4	3.5	2	4.9	4	.6
B 1	7.9	3	.8	5	4.6
2	7.8	M 1	3.7	6	2.4
3	2.6	2	10.0	7	7.0
4	3.2	N 1	2.3	8	NS
C 1	8.5	2	5.8	9	2.3
2	2.2	3	5.1	10	4.4
3	2.3	EB 1	6.5	11	2.8
4	1.4	2	6.6	12	5.9
D 1	15.2	3	6.6	13	3.4
2	4.4	4	9.0	14	1.9
3	4.1	5	3.1	15	4.4
4	2.4	6	5.9	16	2.3
E 1	5.0	7	4.7	17	.8
2	4.5	8	8.5	18	1.4
3	NS	9	3.0	19	4.4
4	.7	10	5.1	20	7.1
F 1	4.4	11	6.5	21	4.1
2	7.7	12	4.2	22	3.9
3	7.3	13	4.0		
G 1	3.4	14	4.0		
2	11.0	WB 1	1.3		
3	.4	2	2.1		
H 1	10.9	3	2.2		
2	2.5	4	4.6		
3	3.2	5	4.4		
I 1	4.3	6	2.8		
2	5.0	7	2.3		
3	3.6	8	5.7		
4	11.4	9	2.4		
J 1	4.8	10	5.2		
2	4.5	11	3.7		
3	9.9	12	2.6		
4	6.3				
5	5.8				
6	4.5				
7	4.0				

NS - No Sample

TABLE 24

% TKN

Location	% TKN	Location	% TKN	Location	% TKN
A 1	.087	K 1	.080	SB 1	.055
2	.146	2	.146	2	.077
3	.064	L 1	.229	3	.085
4	.074	2	.100	4	.024
B 1	.050	3	.090	5	.281
2	.142	M 1	.172	6	.160
3	.068	2	.129	7	.413
4	.048	N 1	.092	8	NS
C 1	.159	2	.223	9	.238
2	.057	3	.162	10	.189
3	.151	EB 1	.177	11	.116
4	.051	2	.295	12	.325
D 1	.246	3	.247	13	.190
2	.231	4	.190	14	.098
3	.054	5	.303	15	.252
4	.049	6	.192	16	.166
E 1	.193	7	.205	17	.052
2	.129	8	.198	18	.092
3	NS	9	.149	19	.246
4	.030	10	.264	20	.347
F 1	.074	11	.253	21	.200
2	.068	12	.179	22	.260
3	.269	13	.302		
G 1	.110	14	.208		
2	.188	WB 1	.107		
3	.033	2	.134		
H 1	.096	3	.142		
2	.078	4	.178		
3	.188	5	.212		
I 1	.086	6	.179		
2	.131	7	.127		
3	.078	8	.195		
4	.136	9	.155		
J 1	.026	10	.145		
2	.057	11	.217		
3	.136	12	.152		
4	.074				
5	.123				
6	.027				
7	.050				

NS - No Sample

TABLE 25 Organic Sediment Index

Location	OSI	Location	OSI	Location	OSI
A 1	.28	K 1	.56	SB 1	.08
2	.67	2	.50	2	.19
3	.24	L 1	1.30	3	.24
4	.26	2	.49	4	.01
B 1	.40	3	.07	5	1.29
2	1.11	M 1	.64	6	.38
3	.18	2	1.29	7	2.89
4	.15	N 1	.21	8	NS
C 1	1.35	2	1.29	9	.55
2	.12	3	.83	10	.83
3	.35	EB 1	1.15	11	.32
4	.07	2	1.94	12	1.92
D 1	3.74	3	1.63	13	.65
2	1.02	4	1.71	14	.19
3	.22	5	.94	15	1.11
4	.12	6	1.13	16	.38
E 1	.96	7	.96	17	.04
2	.58	8	1.68	18	.13
3	NS	9	.45	19	1.08
4	.02	10	1.35	20	2.46
F 1	.32	11	1.64	21	.82
2	.52	12	.75	22	1.01
3	1.96	13	1.21		
G 1	.37	14	.84		
2	2.07	WB 1	.14		
3	.01	2	.28		
H 1	1.05	3	.31		
2	.20	4	.82		
3	.60	5	.93		
I 1	.37	6	.50		
2	.66	7	.29		
3	.28	8	1.11		
4	1.55	9	.37		
J 1	.12	10	.75		
2	.26	11	.80		
3	1.35	12	.40		
4	.47				
5	.71				
6	.12				
7	.20				

NS - No Sample

TABLE 28 Total Volatile Solids ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	38000	K 1	61400	SB 1	46800
2	54500	2	49900	2	36200
3	50300	L 1	79600	3	27200
4	51300	2	68700	4	12700
B 1	54600	3	55500	5	90400
2	54000	M 1	75100	6	80000
3	50200	2	89400	7	111200
4	27700	N 1	57200	8	NS
C 1	85100	2	91700	9	73100
2	52000	3	90100	10	98800
3	44700	EB 1	87500	11	72100
4	27500	2	100500	12	101700
D 1	95000	3	100500	13	85300
2	89400	4	121100	14	51500
3	44600	5	109200	15	100300
4	26000	6	94700	16	93900
E 1	81700	7	107900	17	34200
2	53100	8	109200	18	61300
3	NS	9	72400	19	99300
4	34500	10	104300	20	129100
F 1	69400	11	101400	21	80600
2	44500	12	82300	22	100400
3	98000	13	82200		
G 1	80600	14	80500		
2	95500	WB 1	52400		
3	27300	2	40000		
H 1	78800	3	52600		
2	60900	4	66700		
3	89500	5	71800		
I 1	64200	6	55900		
2	78600	7	51500		
3	68800	8	75600		
4	81100	9	57000		
J 1	63300	10	65600		
2	57100	11	75600		
3	50000	12	57000		
4	63300		4680		
5	81800				
6	58600				
7	55500				

NS - No Sample

TABLE 29 Oil and Grease ELIZABETH RIVER SEDIMENT STUDY

Location	mg/kg	Location	mg/kg	Location	mg/kg
A 1	870	K 1	3100	SB 1	840
2	70	2	3580	2	370
3	110	L 1	3610	3	70
4	ND	2	3130	4	380
B 1	40	3	1160	5	7970
2	320	M 1	1980	6	5020
3	50	2	4060	7	8410
4	ND	N 1	520	8	NS
C 1	80	2	3560	9	2700
2	130	3	4710	10	7800
3	200	EB 1	2260	11	1540
4	410	2	4460	12	7960
D 1	390	3	4670	13	4920
2	90	4	4400	14	530
3	690	5	2560	15	1580
4	850	6	700	16	1210
E 1	3120	7	4390	17	720
2	1870	8	2590	18	950
3	NS	9	1140	19	2860
4	410	10	3220	20	8600
F 1	1330	11	2620	21	1100
2	1190	12	1050	22	1650
3	3220	13	2340		
G 1	1370	14	800		
2	2840	WB 1	1740		
3	150	2	630		
H 1	1820	3	2290		
2	1600	4	2180		
3	2030	5	840		
I 1	1820	6	1060		
2	2550	7	1160		
3	2450	8	1330		
4	1790	9	430		
J 1	1220	10	1270		
2	950	11	1420		
3	250	12	890		
4	770				
5	3050				
6	230				
7	1720				

NS - No Sample
ND - Non-detectable

APPENDIX II

Figure 13

Cadmium

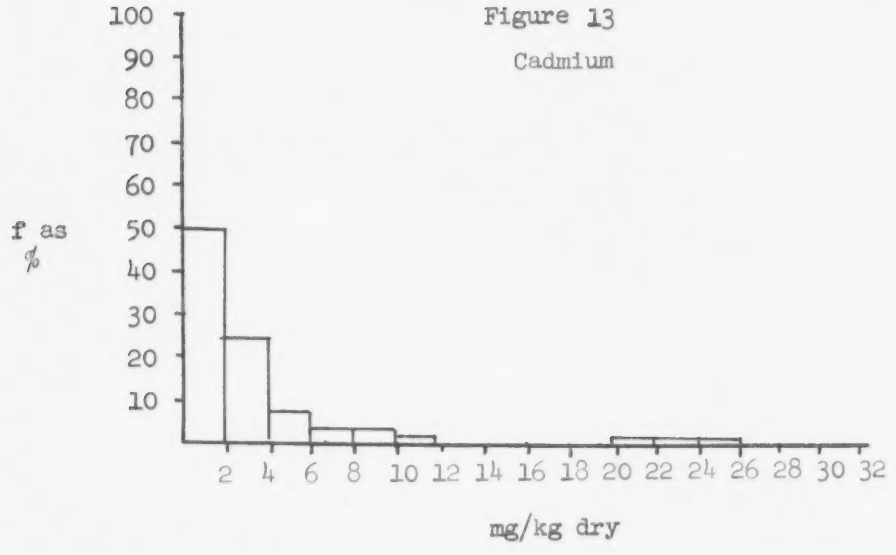


Figure 14

Chromium

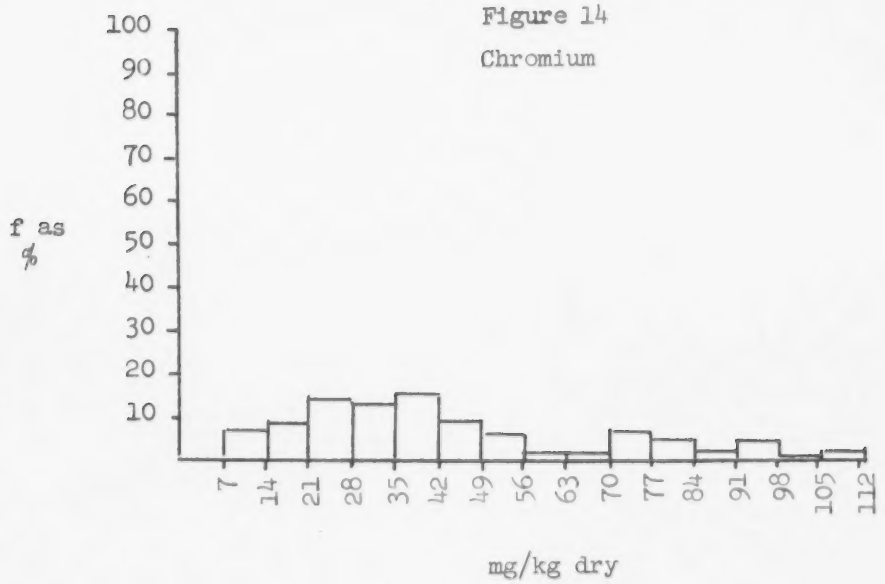


Figure 15

Copper

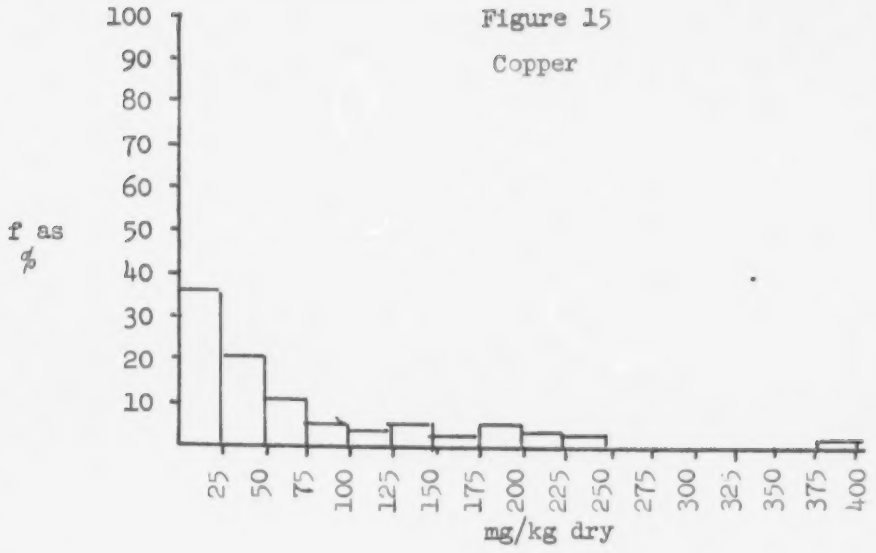


Figure 16

Lead

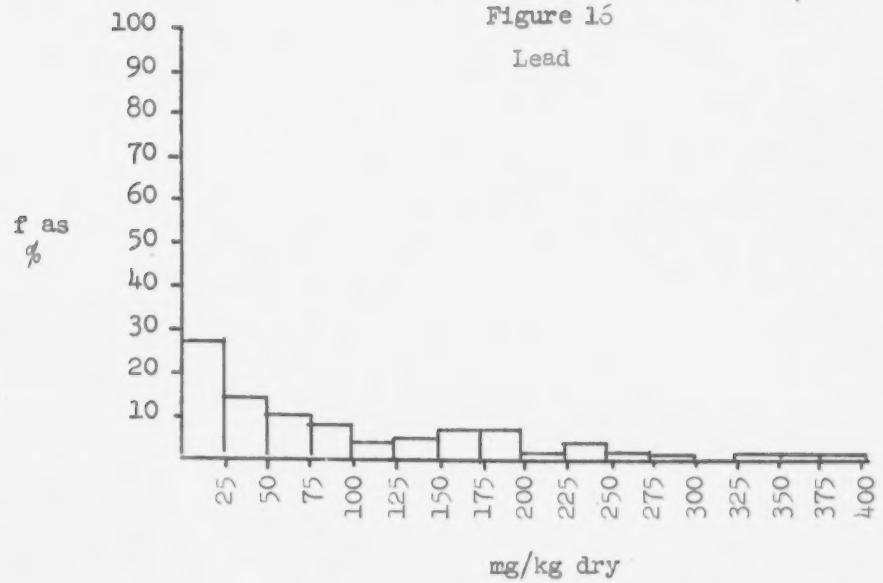


Figure 17

Zinc

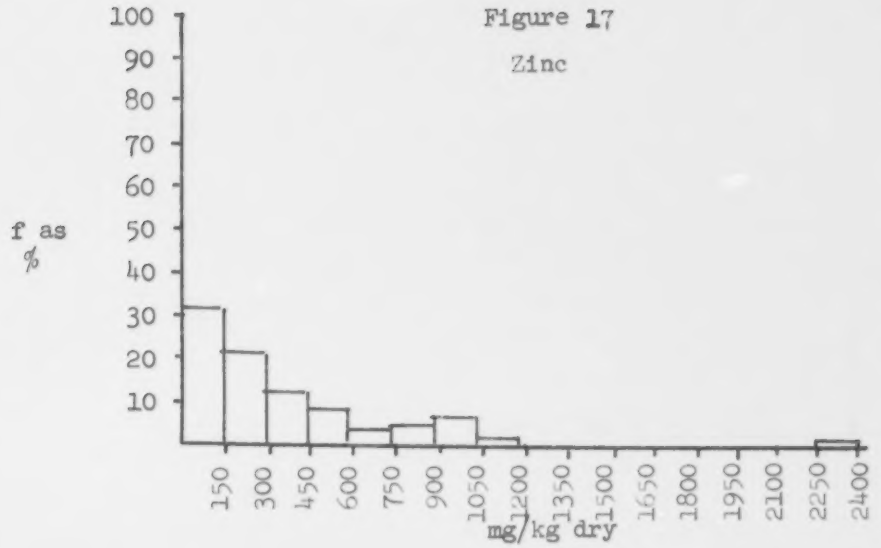


Figure 18

Aluminum

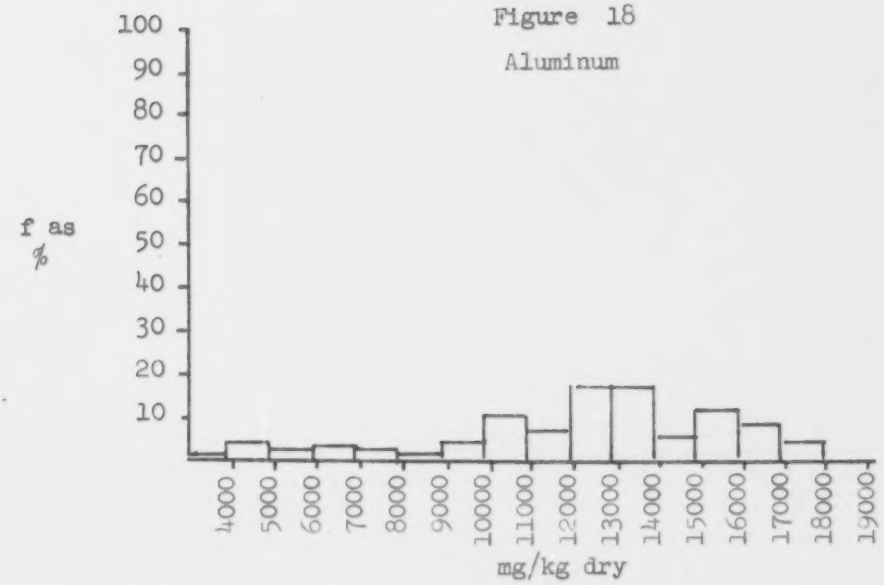


Figure 19

Mercury

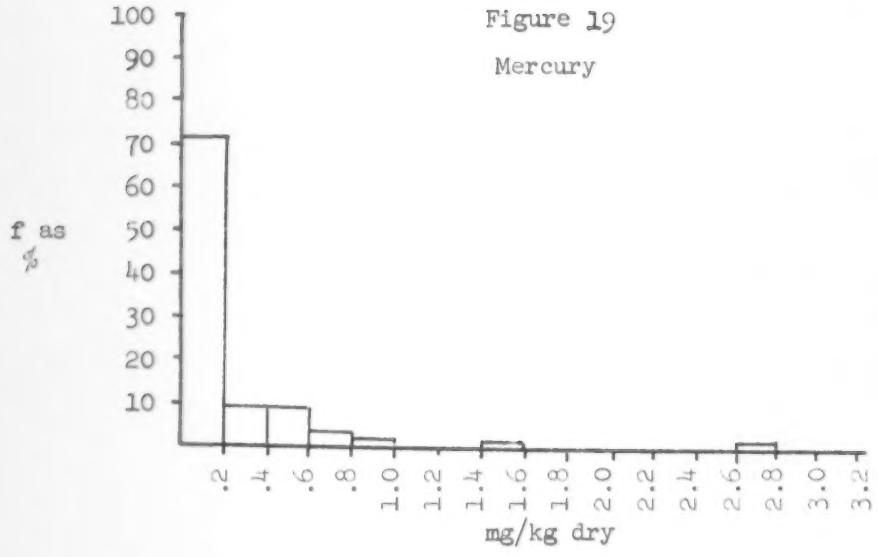
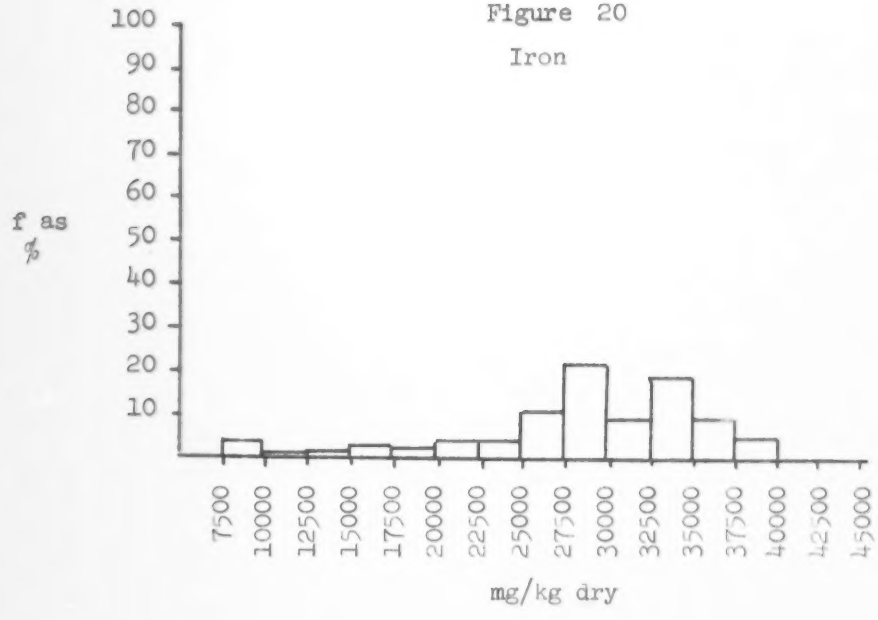


Figure 20

Iron



APPENDIX III

NORFOLK, VIRGINIA DREDGING SITES

Sample Number	Station Location	Core Description
74020701	A 1	dark gray
02	2	medium gray - slight clay
03	3	medium gray clay
04	4	medium gray clay
05	B 1	medium/dark gray - dark bands & medium gray bands
06	2	medium gray clay - some shells
07	3	gray clay - some shells
08	4	light gray - some sand
09	C 1	black - distinct air pockets
10	2	medium gray clay - some shells
11	3	medium gray clay - some sand
12	4	core of 3" - total core - taken as sample sand, worms, large pieces of shell, pebbles
13	D 1	black - air pockets
14	2	black - air pockets
15	3	gray clay - small pebbles, shells
16	4	core of 4" - total core - taken as sample medium gray, sand
17	E 1	black - dark band & medium gray band - sample taken from dark band
18	2	medium gray/black sand - distinct air pockets
19	4	core of 4" - total core - taken as sample light gray clay - very dry, extremely low moisture
20	F 1	medium gray
21	2	black - some sand - air pockets
22	3	black - air pockets
23	G 1	dark gray
24	2	black - air pockets
25	3	core of 5" - total core - taken as sample medium gray with sand - hard
26	H 1	medium gray
27	2	dark gray - varying shades of gray bands
28	3	black with shells - low moisture
29	I 1	medium gray
30	2	medium gray
31	3	dark gray
32	4	black - air pockets
33	J 1	medium gray
34	2	medium gray
35	3	medium gray - some sand
36	4	dark gray with sand
37	5	black - air pockets - heavy gray bottom of core
38	6	sample contains heavy brown clay - some sand - medium gray band and dark gray band
39	7	medium gray - some sand

Sample Number	Station Location	Core Description
74020740	K 1	dark gray/medium gray/dark gray bands - core from first dark band
41	2	dark gray with sand - pulverized dry sample contained fish scales (identity confirmed by AFO biology section)
42	L 1	dark gray
43	2	dark gray
44	3	core of 6" - total core - taken as sample medium gray
45	M 1	dark gray - alternating medium, dark gray and black bands, about 4" each
46	2	black - air pockets
47	N 1	medium gray clay with sand, shells
48	2	black/ dark gray/ medium gray bands - sample taken from black band - air pockets
49	3	black

NORFOLK, VIRGINIA DREDGING SITES

Sample Number	Station Location	Core Description
74021401	EB 1	dark gray, some sand, small pebbles
02	2	black, some shell
03	3	black/dark gray/light gray bands - sample from black band - light gray portion has definite orange streaks
04	4	black
05	5	dark gray, some sand
06	6	dark gray/black bands - sample from dark gray band
07	7	black
08	8	black/dark gray bands - sample from black band
09	9	dark gray, some sand and shell
10	10	black, air pockets
11	11	dark gray, air pockets
12	12	dark gray
13	13	dark gray, some sand
14	14	dark gray, small pebbles
15	WB 1	medium gray, very low moisture
16	2	medium gray, sand and pebbles
17	3	medium gray, low moisture
18	4	medium gray, many shells & organic debris, some sand
19	5	3" core - total taken as sample - dark gray, organic debris
20	6	medium gray, some sand & shell
21	7	3" core - total taken as sample - dark gray, organic debris
22	8	dark gray
23	9	medium gray, some sand
24	10	medium gray
25	11	medium gray
26	12	medium gray
27	SB 1	medium gray-brown/light brown bands - sample from medium gray-brown band - difficult to get sample well-mixed - extremely hard and brittle - almost solid clay - yellow-brown sandy center of core
28	2	dark gray with lots of sand
29	3	4" core - total core taken as sample - dark gray, much sand, small pebbles, organic debris
30	4	light gray with orange streaks - yellow-brown sandy center of core - greenish cast when mixed
31	5	black
32	6	black, center is gray granular
33	7	black, air pockets
34	9	black mixed with light gray clay

Sample Number	Station Location	Core Description
74021435	SB 10	black, air pockets
36	11	medium gray, organic debris (hunk of decaying wood) some sand
37	12	black
38	13	black, air pockets
39	14	dark gray with sand and shell
40	15	black, air pockets
41	16	medium gray/brown with sand
42	17	medium gray clay
43	18	black, light gray granular center, sand
44	19	black, air pockets
45	20	black/brown, some sand, bottom 2" of core sandy brown
46	21	brown with sand, sulfide odor
47	22	brown, large amount of organic debris, some sand

APPENDIX IV

Table 21[1]

TOXICITY OF METALS TO MARINE LIFE

Metal	Chemical Symbol	Range of Concentrations that have Toxic Effects on Marine Life (mg/l or ppm)
Arsenic	As	2.0
Cadmium	Cd	0.01 to 10
Chromium	Cr	1.0
Copper	Cu	0.1
Mercury	Hg	0.1
Lead	Pb	0.1
Nickel	Ni	0.1
Zinc	Zn	10.0

[1]National Estuarine Pollution Study, U.S. Dept. of the Interior, FWPCA, Vol. II, Page IV, 356 (Nov. 3, 1969)

TABLE 22

TRACE METALS - USES AND HAZARDS

Metals	Industrial Use	Health Effects
Arsenic	coal, petroleum, detergents, pesticides, mine tailings	hazard disputed, may cause cancer
Barium	paints, linoleum, paper, drilling mud	muscular and cardiovascular disorders, kidney damage
Cadmium	batteries, paints, plastics, coal, zinc mining, water mains and pipes, tobacco smoke	high blood pressure, sterility, flu-like disorders, cardiovascular disease and hypertension in humans suspected, interferes with zinc and copper metabolism
Chromium	alloys, refractories, catalysts	skin disorders, lung cancer, liver damage
Lead	batteries, auto exhaust from gasoline, paints (prior to 1948)	colic, brain damage, convulsions, behavioral disorders, death
Mercury	coal, electrical batteries, fungicides, electrical instruments, paper and pulp, pharmaceuticals	birth defects, nerve damage, death
Nickel	diesel oil, residual oil, coal, tobacco smoke, chemicals and catalysts, steel and nonferrous alloys, plating	dermatitis, lung cancer (as carbonyl)

REFERENCES

1. Blankenship, William M., personal communication, Dec. 20, 1971.

2. Pheiffer, T.H., D.K. Donnelly, and D.A. Possehl, "Water Quality Conditions in the Chesapeake Bay System," Environmental Protection Agency Technical Report No. 55, Annapolis Field Office (August 1972).

3. Blick, R.A.P., and B. Wisely, "Mortality of Marine Invertebrate Larvae in Hg, Cu, and Zn Solutions," Aust. J. Mar. Freshwat. Res., 18(1):63 (1967).

4. Browning, E., "Toxicity of Industrial Metals," Butterworths, London, England (1961).

5. Corner, E.D.S., and B. W. Sparrows, "The Mode of Action of Toxic Agents. I. Observations on the Poisoning of Certain Crustaceans by Copper and Mercury," Jour. of Mar. Biol. Assoc., V.K. 35,531 (1956).

6. Curley, A., et al., "Organic Mercury Identified as the Cause of Poisoning in Humans and Hogs," Science, 172 (1971).

7. Axelson, G., and P. Magnus, "Renal Damage after Prolonged Exposure to Cadmium," A.M.A. Archives of Environmental Health, Karolinska Institutet, Stockholme, Sweden, p. 360 (1966).

8. Irukayama, K.T. Kondo, F. Kai, and M. Fujiki, "Studies on the origin of the causative agent of Minimata desease. I. Organic mercury compounds in the fish and shellfish from Minimata Bay," Kumamoto Med. J., 14(4), pp. 157-169 (1961).

9. Schroeder, H.A., "Trace Metals and Chronic Diseases," Metal Bindings in Medicine, Lippincott Co., Philadelphia (1960).

10. Kobayashi, J., "Relation between 'Itai-Itai' Disease and the Pollution of River Waters by Cadmium from a Mine," presented at the 5th International Water Pollution Research Conference, held in San Francisco, July-August, 1970, 7 p., 2 Ref., 3 Tab., 6 Fig., U.S.P.H.S., Grant WP-00359 (1970).

11. Faust, S., and J. Hunter (eds), Organic Compounds in Aquatic Environments, Marcel Dekker, Inc., N.Y., Chap. 12 (1971).

12. Oliver, B. "Heavy Metals Levels in Ottawa and Rideau River Sediments," Environmental Science and Technology, 7, No. 2, p. 135 (February 1973).

13. Martin, D., et al., "Distribution of Naturally Occurring Chelators (Humic Acids) and the Selected Trace Metals in some West Coast Florida Streams, 1968-1969," Univ. of South, Florida, Professional Papers Series Number 12, (April 1971).

14. U.S. Army Engineer District, Norfolk, Virginia (Sept. 1973).

15. Harvey, H.D., Jr., E.D. Thoerber, and J.A. Gordon, "Radiological Survey of Hampton Roads, Virginia," Southeastern Radiological Health Laboratory, U.S. Dept. of Health, Education and Welfare, Public Health Service, Bureau of Radiological Health, Montgomery, Alabama (Jan. 1968).

16. Pleasants, J.B., "The Tidal James - A Review," Virginia Institute of Marine Sciences Report No. 18, Applied Marine Science and Ocean Engineering of VIMS, Gloucester Point, Virginia (August 1971).

17. Carpenter, J., personal communication, Johns Hopkins Univ. (1970).

18. Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WPCF, 13th Edition, American Public Health Association, N.Y. (1971).

19. Great Lakes Region Committee on Analytical Methods, "Chemistry Laboratory Manual - Bottom Sediments," FWQA, Environmental Protection Agency (December 1969).

20. Goulden, P.D., and B.K. Afghan, "An Automated Method for Determining Mercury in Water," Technicon Adv. in AutoAnal., 2, p. 317 (1970).

21. Finger, J., personal communication, Southeast Water Laboratory, Analytical Services Section (1970).

22. "Mercury in Water (Automated Cold Vapor Technique)," Environmental Protection Agency, Southeast Water Laboratory, Chemical Services Section (April 1972).

23. Biggs, R.B., "The Sediments of Chesapeake Bay," Estuaries, G.H. Lauff (ed), Publication No. 83, American Association for the Advancement of Science, pp. 230-260 (1967).

24. Smirnow, L.P., "Black Sea Basin," in Habitat of Oil, L.G. Weeks (ed), Am. Assoc. Petrol. Geologists, Tulsa, Oklahoma, pp. 922-994 (1958).

25. Emery, K.O., and S.C. Rittenberg, "Early Diagenesis of California Basin Sediments with Special Reference to the Origin of Oil," Bull. Am. Assoc. Petrol Geologists, 36:735-806 (1952).

26. Van Straaten, L.M.J.U., "Composition and Structure of Recent Marine Sediments in the Netherlands," Leidse, Geol. Mededel, (1954).

27. Manheim, F., "Geochemical Cross-Section of the Baltic Sea," Geochim, Cosmochim. Acta, 25:52-70 (1961).

28. Oppenheimer, C.H., "Bacterial Activity in Sediments in Shallow Marine Bays," Geochim. Cosmochim. Acta., 19(4):1614-1623 (1960).

29. Priddy, R.R., "Recent Mississippi Sounds Sediments compared with some Upper Cretaceous Sediments," Trans. Gulf Coast Assoc. Geol. Soc, 4:159-168 (1954).

30. Biggs, R.B., "Trace Metal Concentration in the Sediments of Baltimore Harbor at Dundalk Marine Terminal," Chesapeake Biological Laboratory, CBL Ref. No. 68-97 (Dec. 1968).

31. Villa, O. and P.G. Johnson, "Distribution of Metals in Baltimore Harbor Sediments," Environmental Protection Agency Technical Report No. 59, Annapolis Field Office (Jan. 1974).

32. Pritchard, D.W., "Salinity Distribution and Circulation in the Chesapeake Bay Estuarine System," J. Marine Res., 11:106-123 (1952).

33. Ryan, J.D., "The Sediments of Chesapeake Bay," Maryland Board of Natural Resources, Dept. of Geol. Mines, Water Resources Bulletin No. 12 (1953).

34. Huggett, R.J., M.E. Bender, and H.D. Slone, "Utilizing Metal Concentration in the Eastern Oyster (Crassostrea Virginica) to Detect Heavy Metal Pollution," Virginia Institute of Marine Sciences Contribution No. 431, Gloucester Point, Virginia (1971).

35. Kopfler, F.C., and J. Mayer, "Studies of Trace Metals in Shellfish," Proceedings, Gulf and South Atlantic Shellfish Sanitation Research Conference, March 1967, Gulf Coast Marine Health Service Laboratory, Dauphic Island, Alabama (1969).

36. Bender, M.E., R.J. Hugget, and J.D. Slone, "Heavy Metals - an Inventory of Existing Conditions," J. Wash. Acad. Sci., Vol. 62, No. 2 (1972).

37. ASTM Manual on Quality Control of Materials, Special Technical Publication 15-C, Jan. 1951.

38. Sommer, S.E., and A.J. Pyzik, "Geochemistry of Middle Chesapeake Bay Sediments from Upper Cretaceous to Present," Chesapeake Sci., Vol. 15, No. 1, p. 39-44, (March 1974).

39. Cross, F.A., et al., "Biogeochemistry of Trace Elements in a Coastal Plain Estuary: Distribution of Mn, Fe and Zn in Sediments, Water, and Polychaetous Worms," Chesapeake Science, Vol. 11, No. 4, p. 221-234 (Dec. 1970).

40. Holmes, C.W., et al., "Migration and Redistribution of Zn and Cd in Marine Estuarine Systems," Environmental Science and Technology, Vol. 8, No. 3, pp. 255-259 (March 1974).

41. Singer, P.C. (ed), Trace Metals and Metal Organic Interactions in Natural Waters, Ann Arbor Science, Michigan (1973).

42. Walter, L.J., Jr., "Transfer of Heavy Metal Pollutants from Lake Erie Bottom Sediments to the Overlying Water," Water Resources Center, Ohio State Univ., Columbus, Ohio (1974).

43. Chesapeake Bilogical Laboratory, "A Biological Inventory of Baltimore Harbor," Natural Resources Institute, Univ. of Md., N.R.I. Ref. No. 71-76 (Sept. 1971).

44. Neilson, B.J, "A Water Quality Study of the Elizabeth River: The Effects of the Army Base and Lambert Point STP Effluents," Special Report No. 75 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, Virginia (May 1975).

45. Drifmeyer, J.E. and W. E. Odum, "Lead, Zinc and Manganese, in Dredge-spoil Pond Ecosystems," Environmental Conservation, Vol. 2, No. 1 (Spring 1975).

46. Richardson, M.D., "Benthic Macroinvertebrate Communities as Indicators of Pollution in the Elizabeth River, Hampton Roads, Virginia," a thesis for the faculty of the school of Marine Science, William and Mary (1971).

47. Boesch, D.F., "Distribution and Structure of Benthic Communities in the Hampton Roads Area, Virginia," a technical ecological report to the Hampton Roads Sanitation District Commission, special report No. 15, Virginia Institute of Marine Science, (April 1971).

48. Bender, M.E., "Physical, Chemical and Biological Features of the Tidal James," Final Report for Task VII-13, Virginia Institute of Marine Science (April 1972).

49. "Lower James River Basin Comprehensive Water Quality Management Study," prepared by Engineering Science Co. for the Virginia State Water Control Board, Planning Bulletin No. 217-B (July 1974).

50. Huggett, R.J., et al., "A Report on the Concentration, Distribution and Impact of Certain Trace Metals from Sewage Treatment Plants on the Chesapeake Bay," CRC Publication No. 31, VIMS Contribution No. 628 (June 1974).

51. Frazier, John M., "The Dynamics of Metals in the American Oyster, Crassostrea virginica. 1. Seasonal Effects," Chesapeake Science, Vol. 16, No. 3, p. 162-171 (Sept. 1975).

52. "James River Comprehensive Water Quality Management Study," Vol. VII- 8 & 9 Section A - Existing Data Base for Industrial Wastewater Management Systems, Commonwealth of Virginia Water Control Board (May 1973).

53. Ballinger, D.G., and G.D. McKee, "Chemical Characterization of Bottom Sediments," Journal of Water Pollution Control Federation, Vol. 43, No. 2, p. 216-227 (February 1971).

54. Carmody, D.J., Pearce, J.B., and W.E. Yasso, "Trace Metals in Sediments of the New York Bight," Mar. Poll. Bull., 4(9), p. 132-135 (1973).

55. Frazier, J.M., "Current Status of Knowledge of the Biological Effects of Heavy Metals in the Chesapeake Bay," Chesapeake Science, 13 (Supplement), p 5149-53 (1972).